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Checked By	D. Van		Drawing No. SED46117400 – 301	
Title	Refrigerated Centrifuge (RC) Stress Analysis Report		Report No. LMSEAT 33513	

ABSTRACT

This report contains the stress analysis of the Refrigerated Centrifuge (RC) Assembly, P/N SED46117400-301 for the Human Research Facility (HRF) project.

The refrigerated centrifuge is intended to provide a system of separation of biological samples based on differing sample densities in a controlled temperature environment. RC will be a Commercial-Off-The-Shelf (COTS) unit, repackaged into a 12 Panel Unit (PU) drawer. It consists of two main components: (1) the refrigeration system and (2) the rotor assembly. The refrigeration method utilized by the centrifuge is vapor compression cycle. Vapor compression system consists of four components: compressor, condenser, evaporator, and expansion device.

During launch, landing, and on-orbit operation, the RC shall be rack mounted in a 12 PU active drawer. The refrigerated centrifuge will be used to separate biological samples such as blood and saliva. The front panel of the 12 PU drawer will open to expose the centrifuge rotor. The crewmember will select a rotor as identified in the experimental protocol procedures. The rotor is removed and replaced with the use of an Allen wrench that is provided as part of the centrifuge system. The samples will be loaded, and the door will be closed. The controls will be set for the appropriate time, temperature, rotor speed, and ramp up and down speeds.

A finite element model (FEM) is constructed to represent the RC Assembly. Quasi-static liftoff and landing load factors are obtained from Space Station Program (SSP) Pressurized Payloads Interface Requirements Document [2]. Model mass participation method is used to calculate the random loads with the fundamental frequencies obtained from the constrained normal mode analysis of the finite element model. Crew-induced loads analysis, fail-safe analysis, safe return configuration analysis, depressurization/repressurization analysis, and containment analysis are also included in this report.

Structural analysis is performed based on the requirements in the Structural Verification Plan for Human Research Facility Payloads and Racks, LS-71012. Positive margins of safety have been obtained for all structural members of the RC. The result indicates that the RC assembly satisfies the structural requirements for the Space Station or any mission in which the analysis loads are not exceeded. The analysis also shown the RC has a fatigue life of 16 missions.

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LIST OF SYMBOLS

Generally, symbols are defined as they appear within the body of the text.

CRES	Corrosion Resistant Steel
CSA	Computerized Structural Analysis (and Research Corporation)
EXPRESS	EXpedite the PRocessing of Experiments to Space Station
FEM	Finite Element Model
f_n	Natural frequencies
FORTRAN	Formula Translator software
FS	Factor of Safety
g(s)	Gravitational Acceleration
HRF	Human Research Facility
Hz	Hertz (cycles per second)
IDD	Interface Definition Document
in	Inch(es)
in-lb	Inch pound
in^2	Square inch
ISPR	International Standard Payload Rack
ISS	International Space Station
ISSP	International Space Station Program
ksi	Kilopounds per square inch
lb	Pounds(s)
lb-in	Pound-inch
MPLM	Mini-Pressurized Logistics Module
MOS	Margin of Safety
MS	Margin of Safety
NAS	National Aerospace Standard
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analysis software program
PLD	Preload
PSD	Power Spectral Density
psi	Pounds per square inch
Q	Amplification Factor

LIST OF SYMBOLS *Concluded*

RC	Refrigerated Centrifuge
RVLF	Random Vibration Load Factor
SDRC	Structural Dynamics and Research Corporation

REFERENCES

1. LS-71012, Structural Integrity Verification Plan for Human Research Facility Payloads and Racks, NASA JSC, August 1999.

2. SSP 57000, Pressurized Payloads Interface Requirements Document, Revision D, NASA JSC, July 21, 1999.

3. SSP-52005, ISS Payload Flight Equipment Requirements and Guidelines for Safety-Critical Structures, Revision B, NASA JSC, December 10, 1998.

4. SSP 52000-IDD-ERP, EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document, Initial Baseline Release, NASA JSC, May 27, 1998.

5. NSTS 14046, Payload Verification Requirements, Revision D, NASA JSC, July 1997.

6. NASA-STD-5003, Fracture Control Requirements for Payloads Using the Space Shuttle, NASA, October 7, 1996.

7. LS-71010, Fracture Control Plan for Human Research Facility Payloads and Racks, NASA JSC, February 1999.

8. NSTS/ISS 18798, Interpretations of NSTS/ISS Payload Safety Requirements, Revision B, NASA JSC, September 1997.

9. MIL-HDBK-5H, Military Standardization Handbook, Metallic Materials and Elements for Aerospace Vehicle Structures, United States Department of Defense, December 1998.

10. NSTS 08307, Criteria for Preloaded Bolts, Revision B, NASA JSC, July 6, 1998.

11. SM-G-SE-13, Design Tables for Fastener Torque, Martin Marietta Services, Webster, Texas, June 1994.

12. <u>Analysis and Design of Flight Vehicle Structures</u>, Bruhn, E.F., Jacobs Publishing, Indianapolis, Indiana, 1973.

13. <u>Roark's Formulas for Stress and Strain</u>, 6th Edition, Young, Warren C., McGraw-Hill Book Company, New York, 1989.

14. <u>Mechanical Engineering Design</u>, 5th Edition, Shigley and Mitchell, McGraw-Hill, New York, 1989.

15. CSA/NASTRAN User's Manual, Computerized Structural Analysis and Research Corporation (CSAR), March, 1997.

1.0 INTRODUCTION

This report contains the stress analysis of the RC (SED46117400-301). The refrigerated centrifuge will be flown in the HRF Rack 2 in MPLM. Loads used in the analyses are obtained from Reference 2. The random load factors are calculated using the modal mass participation method. The Power Spectral Densities (PSDs) are obtained from Reference 2.

The refrigerated centrifuge is intended to provide a system of separation of biological samples based on differing sample densities in a controlled temperature environment. RC will be a Commercial-Off-The-Shelf (COTS) unit, repackaged into a 12 Panel Unit (PU) drawer. It consists of two main components: (1) the refrigeration system and (2) the rotor assembly. The refrigeration method utilized by the centrifuge is vapor compression cycle. Vapor compression system consists of four components: compressor, condenser, evaporator, and expansion device.

During launch, landing, and on-orbit operation, the RC shall be rack mounted in a 12 PU active drawer. The refrigerated centrifuge will be used to separate biological samples such as blood and saliva. The front panel of the 12 PU drawer will open to expose the centrifuge rotor. The crewmember will select a rotor as identified in the experimental protocol procedures. The rotor is removed and replaced with the use of an Allen wrench that is provided as part of the centrifuge system. The samples will be loaded, and the door will be closed. The controls will be set for the appropriate time, temperature, rotor speed, and ramp up and down speeds.

The coordinate system of the RC Assembly and its Finite Element Model (FEM) are shown in Figures 3-2 through 3-14. The FEM of the item is described in Section 3.0 of this report. The total measured weight of the RC is TBD lb. A FEM weight of 158.53 lb including 10.0 lb of stowage mass is used in the analysis.

Analyses are performed by finite element techniques augmented with hand analyses where appropriate. Untested Factors of Safety (FS) of 2.0 for ultimate and 1.25 for yield are used for all the members. For fail-safe analysis, a factor of safety of 1.0 is used. A factor of safety of 1.4 for ultimate is used for the safe return configuration analysis.

Positive margins of safety have been obtained for all structural members of the RC. The result indicates that the RC assembly satisfies the structural requirements for the Space Station or any mission in which the analysis loads are not exceeded. The analysis also shown the RC has a fatigue life of 16 missions.

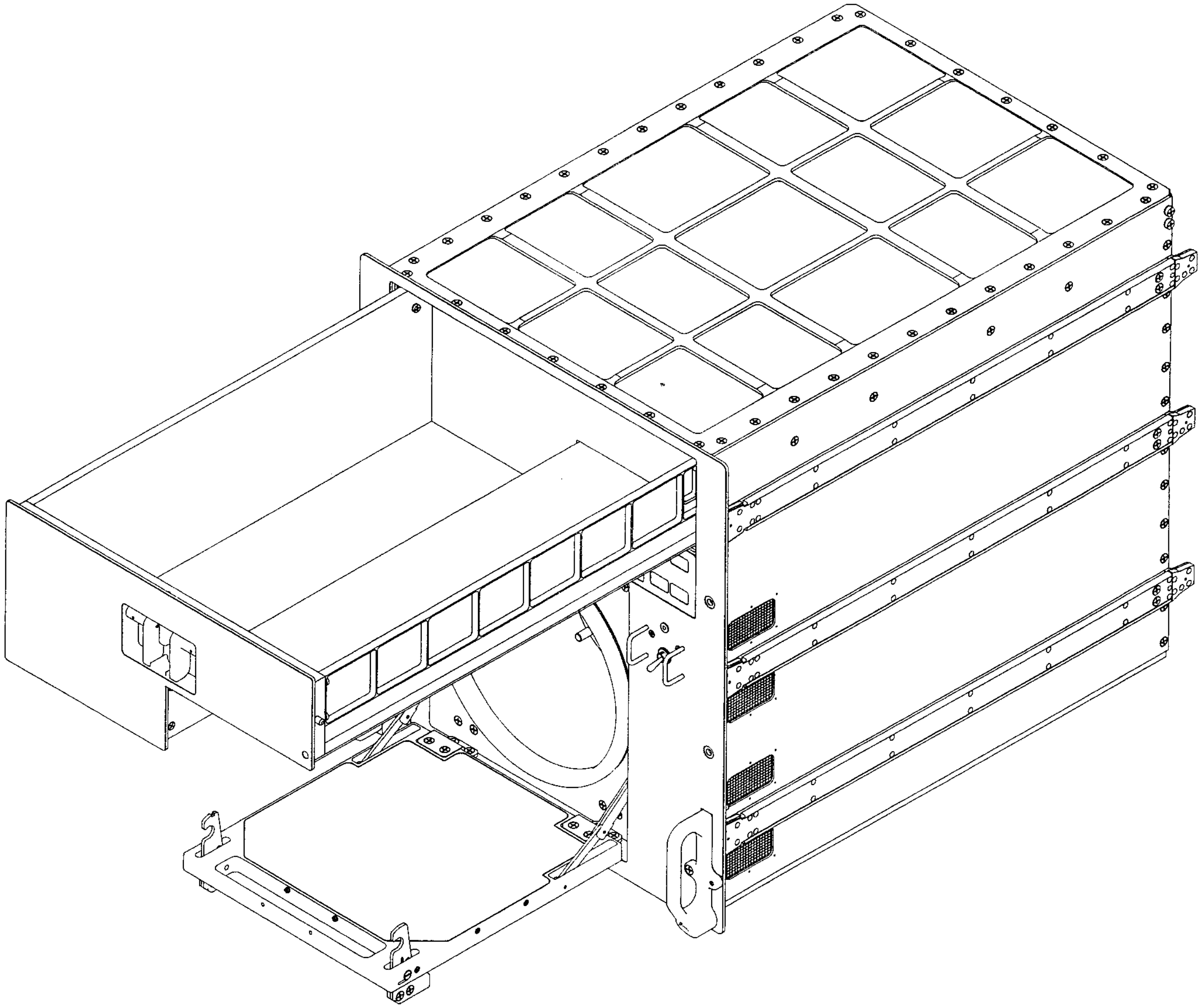


Figure 1-1 Refrigerated Centrifuge (RC) Assembly Isometric View

2.0 MINIMUM MARGINS OF SAFETY

Factors of safety for liftoff, landing, and kick-loads are 2.0 for ultimate and 1.25 for yield for all untested components. For fail-safe conditions, an ultimate factor of safety of 1.0 was used for all components. A factor of safety of 1.4 is used for the safe return configuration analysis. The minimum factor of safety for structural component design for the RC for flight environments are in accordance with SSP 52005, Rev. B, Table 5.1.2-1. Table 2.1 summarized the FS used in the analysis.

Table 2.1 Factor of Safety Summary

EVENT	LOAD / STRESS MODE	FACTOR OF SAFETY	
		YIELD	ULTIMAT
Liftoff / Landing	Maximum Principal stress or Von Mises stress or Combined Tension and Shear loads		
- Untested Structure		1.25	2.0
- Fail-safe			1.0
- Safe Return			1.4
- Fasteners		1.25	2.0
Crew Induced Loads	Kick Load	1.25	2.0

Positive margins of safety, based on the above factors of safety, have been obtained from the analysis. Table 2.2 presents the minimum margins for all structural components for the RC.

Table 2.2 Minimum Margins Of Safety Summary

ITEM AND PART NUMBER OR DRAWING NUMBER	MATERIAL	LOAD/ STRESS MODE	APPLIED STRESS/ LOAD	ALLOWABLE STRESS/ LOAD	MINIMUM MOS	REFERENCE PAGE
PANELS:						
Top Panel SDG46114565-001	7075-T7351 Aluminum	Principal	1874.52 psi	68000 psi (ultimate)	17.14	5-19
Bottom Panel SDG46117378-301	7075-T7351 Aluminum	Principal	28382.61 psi	68000 psi (ultimate)	0.20	5-21
Right Side Panel SDG46117367-301	7075-T7351 Aluminum	Principal	17873.81 psi	68000 psi (ultimate)	0.90	5-24
Left Side Panel SDG46117367-301	7075-T7351 Aluminum	Principal	16080.33 psi	68000 psi (ultimate)	1.11	5-26
Front Panel SDG46117366-301	7075-T7351 Aluminum	Principal	30583.07 psi	68000 psi (ultimate)	0.11	5-7
Rear Panel SDG46117369-301	7075-T7351 Aluminum	Principal	24208.72 psi	68000 psi (ultimate)	0.40	5-28
Front Door SEG46117371-301	7075-T7351 Aluminum	Principal	2684.82 psi	68000 psi (ultimate)	11.66	5-29
Stowage Drawer SEG46117716-301	7075-T7351 Aluminum	Principal	12293.20 psi	68000 psi (ultimate)	1.77	5-10
Floating Plate SDG46117388-301	7075-T7351 Aluminum	Principal	3068.27 psi	68000 psi (ultimate)	10.08	5-11
Support Assembly SDG46117390-301	7075-T7351 Aluminum	Principal	13091.46 psi	68000 psi (ultimate)	1.60	5-12
Motor Mounting Ring SDG46117391-301	7075-T7351 Aluminum	Principal	5733.51 psi	68000 psi (ultimate)	4.93	5-13
Slides SEG46117459-301	7075-T7351 Aluminum	Principal	12834.64 psi	68000 psi (ultimate)	1.65	5-30

NOTE: Factor of safety of 2.0 for ultimate, 1.25 for yield.

Table 2.2 Minimum Margins of Safety Summary *(Continued)*

ITEM	PART NUMBER MATERIAL	LOAD MODE	APPLIED LOAD	ALLOWABLE LOAD	MINIMUM MOS	REFERENCE PAGE
FASTENERS:						
Top Panel to Front Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	20.43 lbs 29.33 lbs	2400.0 lbs 1685.0 lbs	0.47 (yield)	5-38
Top Panel to Rear Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	33.34 lbs 8.54 lbs	2400.0 lbs 1685.0 lbs	0.47 (yield)	5-39
Top Panel to Right Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	53.91 lbs 8.24 lbs	2400.0 lbs 1685.0 lbs	0.77 (yield)	5-40
Top Panel to Left Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	47.76 lbs 6.65 lbs	2400.0 lbs 1685.0 lbs	0.47 (yield)	5-41
Bottom Panel to Front Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	169.04 lbs 178.25 lbs	2400.0 lbs 1685.0 lbs	0.44 (yield)	5-42
Bottom Panel to Rear Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	587.58 lbs 22.07 lbs	2400.0 lbs 1685.0 lbs	0.38 (yield)	5-43
Bottom Panel to Right Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	543.22 lbs 90.80 lbs	2400.0 lbs 1685.0 lbs	0.39 (yield)	5-44
Bottom Panel to Left Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	454.92 lbs 160.01 lbs	2400.0 lbs 1685.0 lbs	0.40 (yield)	5-45
Front Panel to Right Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	258.29 lbs 424.87 lbs	2400.0 lbs 1685.0 lbs	0.35 (yield)	5-46
Front Panel to Left Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	397.29 lbs 513.39 lbs	2400.0 lbs 1685.0 lbs	0.28 (yield)	5-47
Rear Panel to Right Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	160.28 lbs 92.72 lbs	2400.0 lbs 1685.0 lbs	0.45 (yield)	5-48
Rear Panel to Left Side Panel	NAS1102-3 CRES A286	Combined Tension: Shear:	254.85 lbs 137.74 lbs	2400.0 lbs 1685.0 lbs	0.43 (yield)	5-49
Stowage Drawer Panel Connection	NAS1101-08 NAS1102-08 CRES A286	Combined Tension: Shear:	160.84 lbs 188.79 lbs	1769.0 lbs 1240.0 lbs	0.17 (yield)	5-50

NOTE: Factor of safety of 2.0 for ultimate, 1.25 for yield.

Table 2.2 Minimum Margins of Safety Summary *(Continued)*

ITEM	PART NUMBER MATERIAL	LOAD MODE	APPLIED LOAD	ALLOWABLE LOAD	MINIMUM MOS	REFERENCE PAGE
FASTENERS:						
Right Slide to Right Side Panel	NAS1101-3 CRES A286	Combined Tension: Shear:	366.59 lbs 121.22 lbs	2400.0 lbs 1685.0 lbs	0.41 (yield)	5-51
Left Slide to Left Side Panel	NAS1101-3 CRES A286	Combined Tension: Shear:	624.19 lbs 233.70 lbs	2400.0 lbs 1685.0 lbs	0.36 (yield)	5-52
Support Assy. to Side Panel	NAS1101-3 CRES A286	Combined Tension: Shear:	269.92 lbs 89.42 lbs	2400.0 lbs 1685.0 lbs	0.43 (yield)	5-53
Support Assy. to Centrifuge Assy.	NAS1101-3 CRES A286	Combined Tension: Shear:	269.47 lbs 64.89 lbs	2400.0 lbs 1685.0 lbs	0.43 (yield)	5-54
Centrifuge Assy. to Front Panel	NAS1101-3 CRES A286	Combined Tension: Shear:	300.52 lbs 96.07 lbs	2400.0 lbs 1685.0 lbs	0.43 (yield)	5-55
Floating Plate to Bottom Panel	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	1433.09 lbs 239.19 lbs	4368.0 lbs 3034.0 lbs	0.14 (yield)	5-56
Motor Ring to Support Assy.	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	78.47 lbs 77.84 lbs	4368.0 lbs 3034.0 lbs	0.23 (yield)	5-57
Front Panel to Rack Post	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	278.08 lbs 659.65 lbs	4368.0 lbs 3034.0 lbs	0.18 (yield)	5-58

NOTE: Factor of safety of 2.0 for ultimate, 1.25 for yield.

Table 2.2 Minimum Margins Of Safety Summary *(Continued)*

ITEM AND PART NUMBER OR DRAWING NUMBER	MATERIAL	LOAD/ STRESS MODE	APPLIED LOAD/ STRESS	ALLOWABLE LOAD/ STRESS	MINIMUM MOS	REFERENCE PAGE
CREW INDUCED LOADS:						
Sto. Drawer Front SDG46117717-301	7075-T7351 Aluminum	Kick 125 lbs.	18420.51 psi	68000.0 psi	0.85 (ultimate)	6-2
Front Door SED46117371-301	500 Lexan	Kick 125 lbs.	1115.89 psi	9600.0 psi	3.30 (ultimate)	6-4
Front Handle SED46117911-301	6061-T6 Aluminum	Kick 50 lbs.	11942.42 psi	42000.0 psi	0.76 (ultimate)	6-5
FAIL SAFE:						
Front Panel to Rack Post	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	509.44 lbs 672.04 lbs	5824.0 lbs 4046.0 lbs	0.58 (ultimate)	7-1
Front Panel SDG46117371-301	7075-T7351 Aluminum	Principal	30583.07 psi	68000 psi (ultimate)	1.22	7-2
Slide to Side Panel	NAS1101-3 CRES A286	Combined Tension: Shear:	1011.18 lbs 193.10 lbs	3200.0 lbs 2246.0 lbs	0.80 (ultimate)	7-5
Slides SEG46117459-301	7075-T7351 Aluminum	Principal	11102.07 psi	68000 psi (ultimate)	5.12	7-4
Floating Plate to Bottom Panel	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	1902.13 lbs 314.84 lbs	5824.0 lbs 4046.0 lbs	0.52 (ultimate)	7-6
Floating Plate SDG46117388-301	7075-T7351 Aluminum	Principal	13316.76 psi	68000 psi (ultimate)	4.11	7-6
Motor Ring to Support Assy.	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	477.71 lbs 40.93 lbs	5824.0 lbs 4046.0 lbs	0.61 (ultimate)	7-7
Motor Ring SDG46117391-301	7075-T7351 Aluminum	Principal	29983.62 psi	68000 psi (ultimate)	1.27	7-7
Power Controller to Bottom Panel	NAS1101-3 CRES A286	Combined Tension: Shear:	402.60 lbs 572.64 lbs	3200.0 lbs 2246.0 lbs	0.58 (yield)	7-8
Compressor to Floating Plate	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	259.57 lbs 472.78 lbs	5824.0 lbs 4046.0 lbs	0.62 (yield)	7-10
Condenser to Floating Plate	NAS1101-3 CRES A286	Combined Tension: Shear:	93.32 lbs 91.12 lbs	3200.0 lbs 2246.0 lbs	0.95 (ultimate)	7-12

NOTE: Factor of safety of 2.0 for ultimate, 1.25 for yield and 1.0 for fail-safe.

Table 2.2 Minimum Margins Of Safety Summary *(Concluded)*

ITEM AND PART NUMBER OR DRAWING NUMBER	MATERIAL	LOAD/ STRESS MODE	APPLIED LOAD/ STRESS	ALLOWABLE LOAD/ STRESS	MINIMUM MOS	REFERENCE PAGE
SAFE RETURN CONFIGURATION ANALYSIS:						
Floating Plate to Bottom Panel	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	1902.13 lbs 314.84 lbs	5824.0 lbs 4046.0 lbs	0.47 (ultimate)	8-2
Floating Plate SDG46117388-301	7075-T7351 Aluminum	Principal	13316.76 psi	68000 psi (ultimate)	2.65	8-2
Motor Ring to Support Assy.	NAS1351N4 Heat-Res. Steel	Combined Tension: Shear:	477.71 lbs 40.93 lbs	5824.0 lbs 4046.0 lbs	0.60 (ultimate)	8-3
Motor Ring SDG46117391-301	7075-T7351 Aluminum	Principal	29983.62 psi	68000 psi (ultimate)	0.62	8-3

NOTE: Factor of safety of 1.4 for safe return configuration analysis.

3.0 MODEL DESCRIPTION

A FEM of the RC Assembly was created using Structural Dynamics Research Corporation (SDRC) Integrated Design Engineering Analysis Software (I-DEAS). The FEM was developed to facilitate the dynamic and stress analysis of the item.

The FEM for the RC Assembly is a collection of 12,658 nodes and 13,493 elements as shown in Figures 3-2 through 3-14. The mainframe assembly consists of the top panel, bottom panel, two side panels, front panel, and rear panel. The subassembly and the main internal components are front door, stowage drawer, floating plate, centrifuge assembly, support assembly, motor mounting ring, and slides. All the panels are modeled as quad elements and the stiffeners as bar elements. Most of the fastener connections are modeled as bar elements. Internal components, compressor, condenser, motor, and power controller module are modeled as single concentrated masses on rigid elements. The RC Assembly measures 16.751 inches wide, 24.125 inches long, 20.687 inches high, and weighs 158.53 lb including 10 lb of stowage mass. The model was built based on Drawing Number SED46117400-301.

Geometry
The overall geometry of the RC Assembly FEM is described in terms of basic rectangular Cartesian coordinate system. The origin of the system is located at the lower left corner of the front panel. The X-axis is in the direction of the 16-inch dimension and is parallel to the front of drawer. The Y-axis is in the direction of the 24-inch dimension and is positive toward the back of the drawer. The Z-axis is in the direction of the 20-inch dimension and is positive toward the top panel.

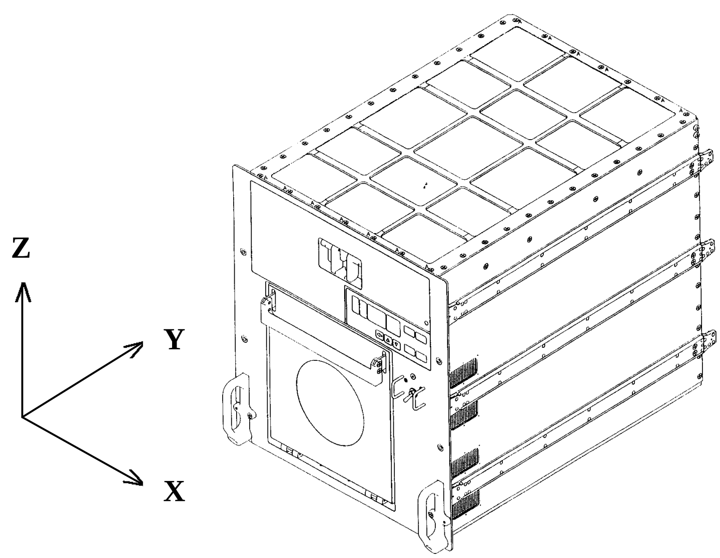


Figure 3-1 RC Coordinate System

3.0 MODEL DESCRIPTION *(Concluded)*

Units

Model units are pounds for force, inches for length, and seconds for time.

Material Properties

The material properties used in the RC FEM during stress analysis are listed in Appendix A.

Mass Properties

Table 3.1 lists the RC FEM mass properties. Mass is listed in pounds and center of gravity (cg) location in inches. The origin of the system is located at the lower left corner of the front panel.

Table 3.1 RC Finite Element Mass Properties

Mass (lb)	Center of Gravity		
	X (inches)	Y (inches)	Z (inches)
158.532	9.181	12.476	8.196

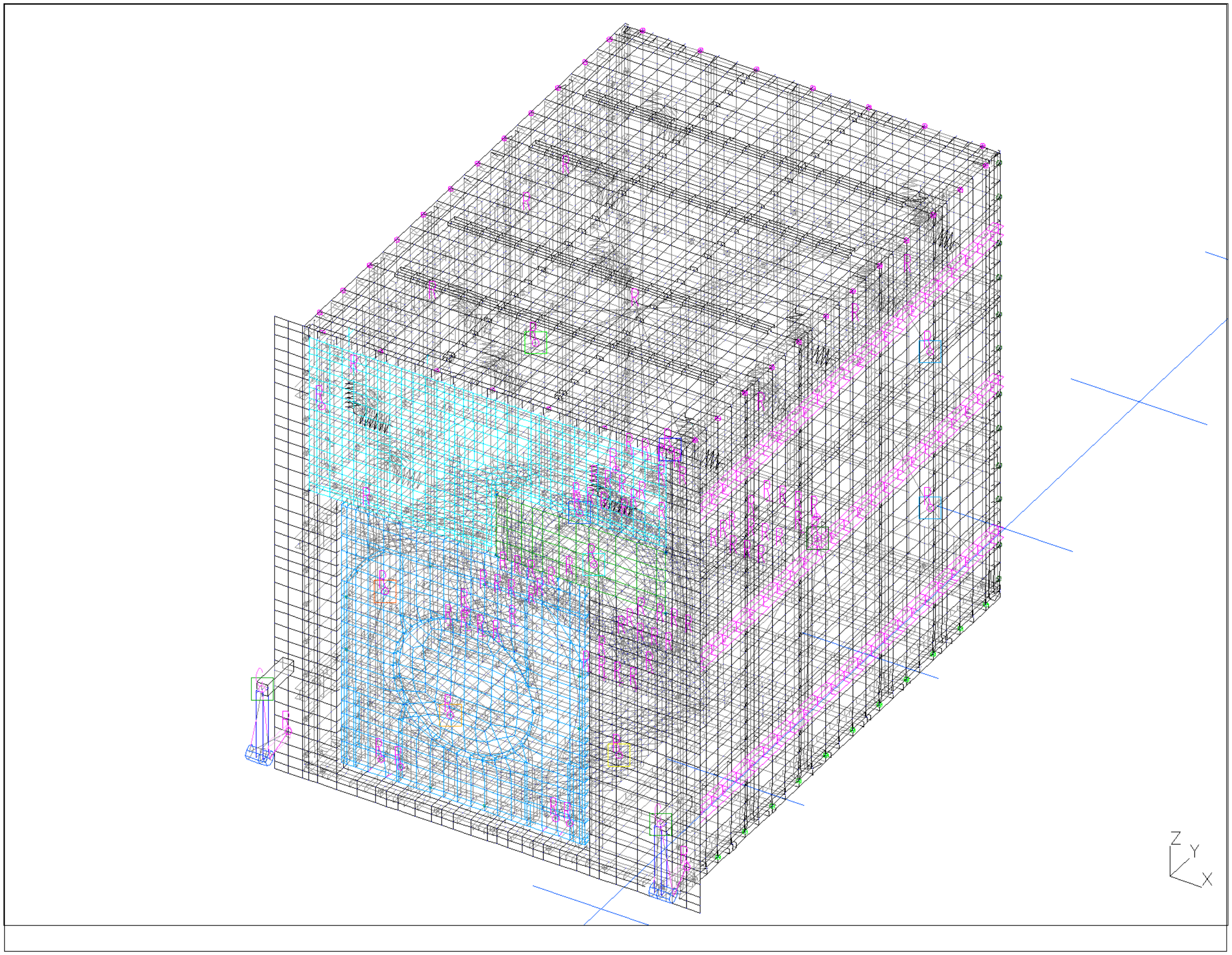


Figure 3-2 Refrigerated Centrifuge FEM

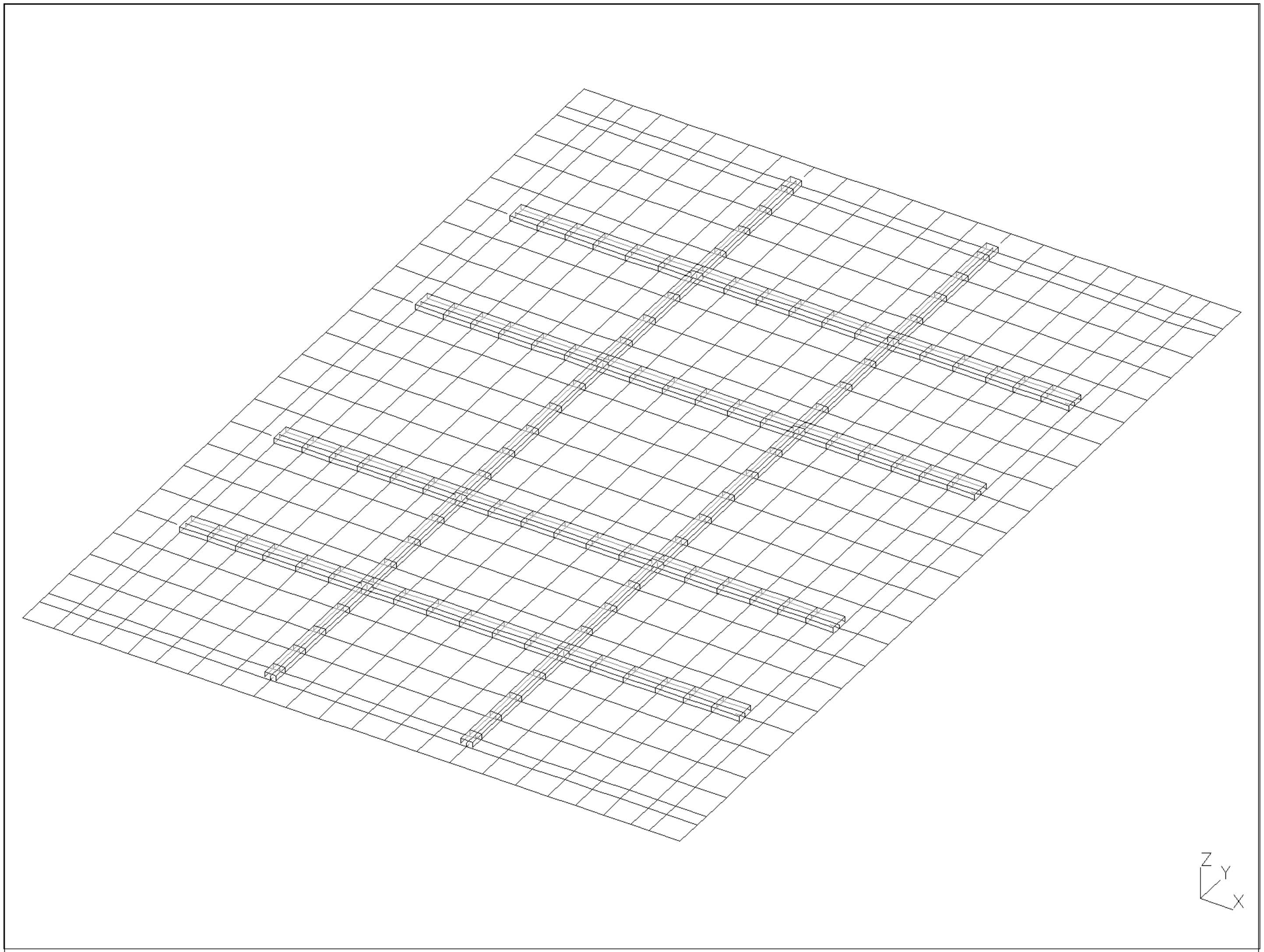


Figure 3-3 RC Top Panel FEM

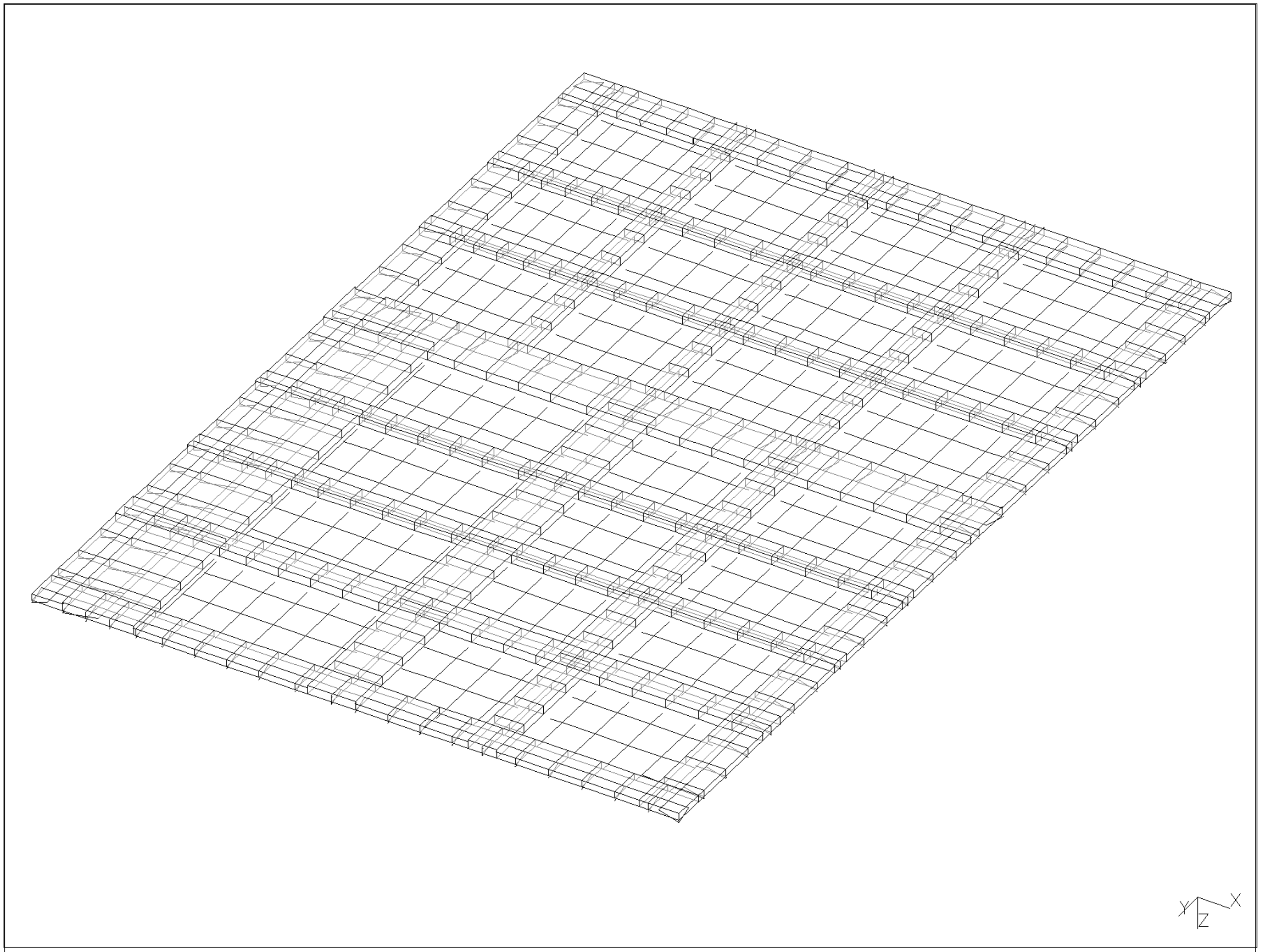


Figure 3-4 RC Bottom Panel FEM

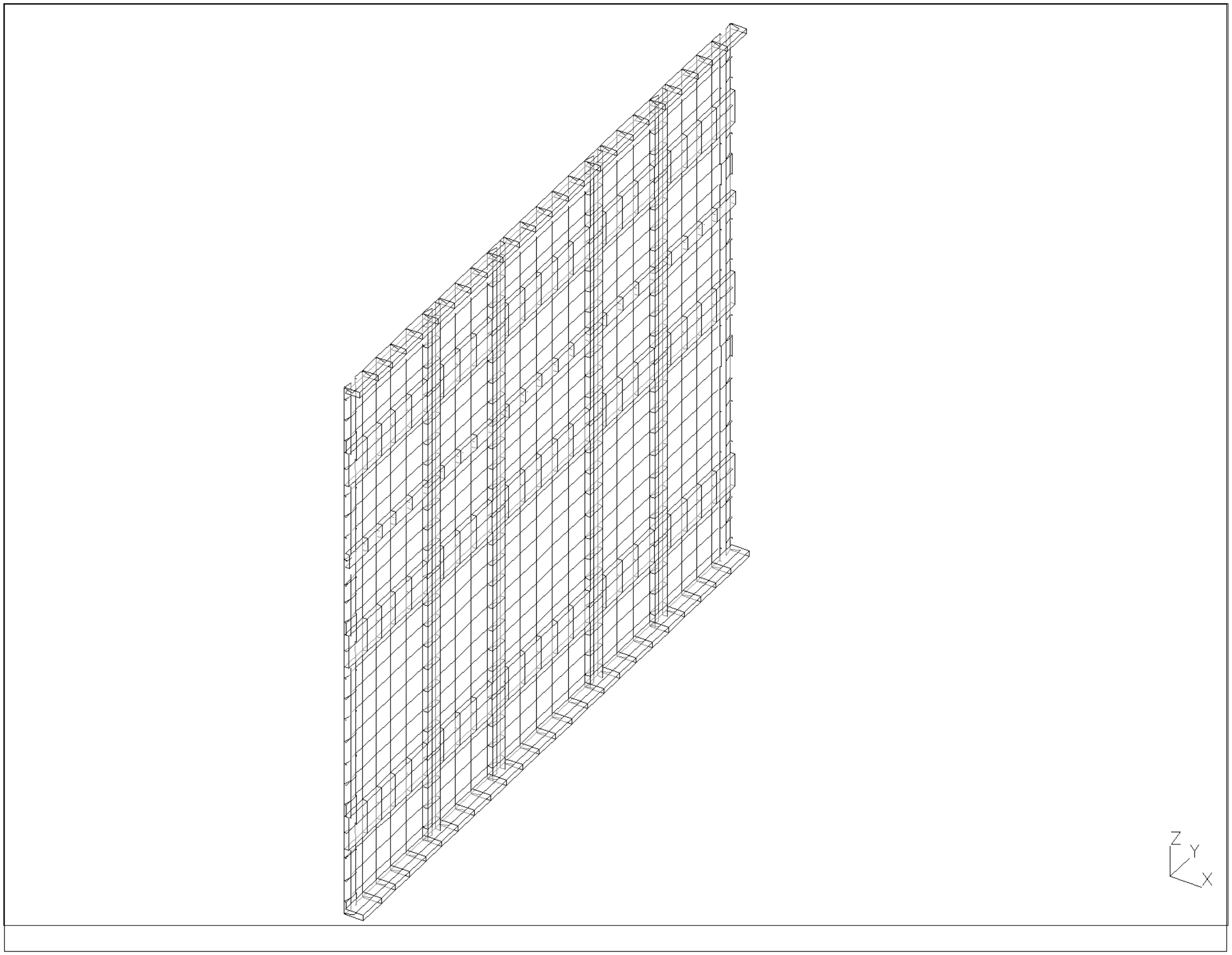


Figure 3-5 RC Left Side Panel FEM

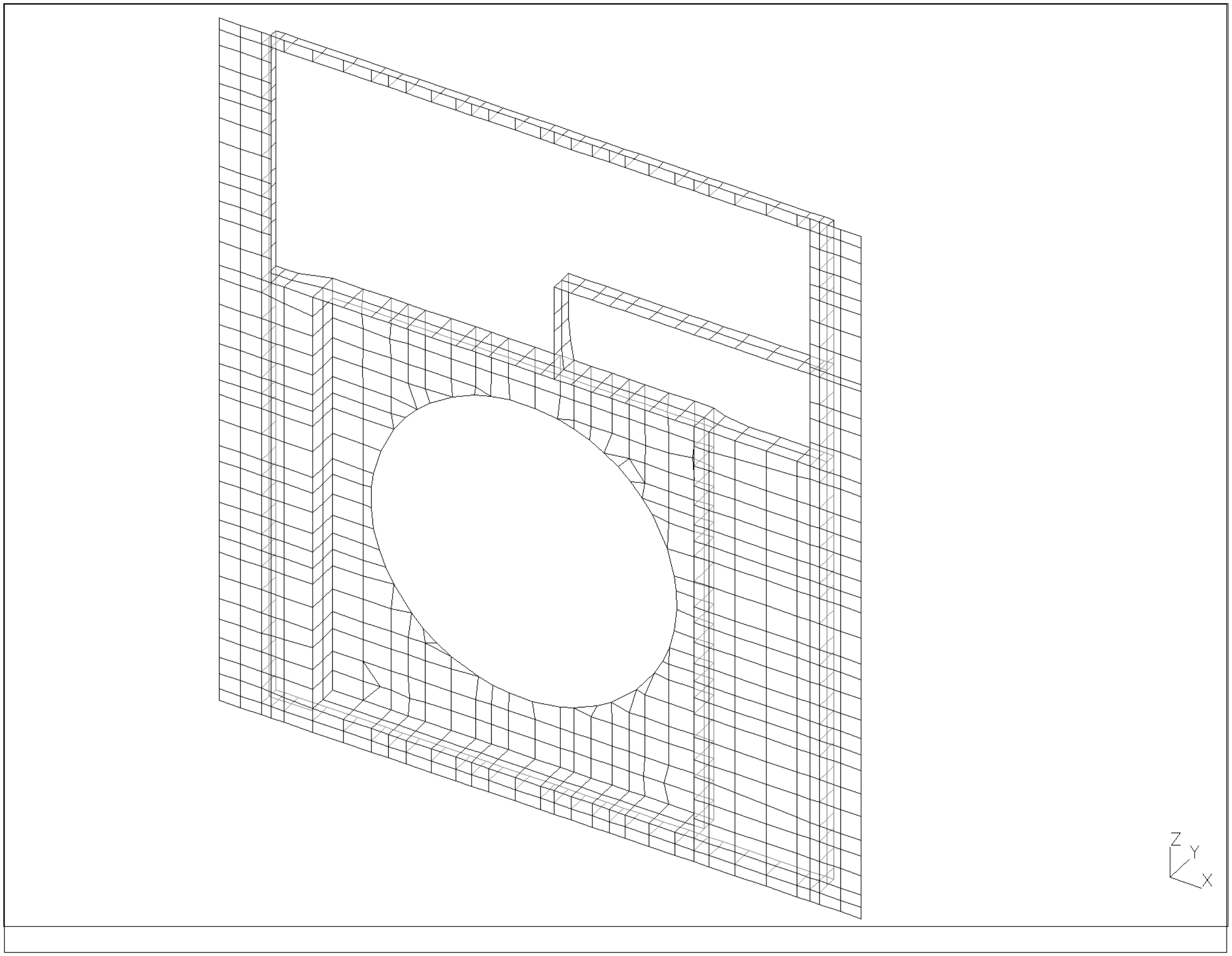


Figure 3-6 RC Front Panel FEM

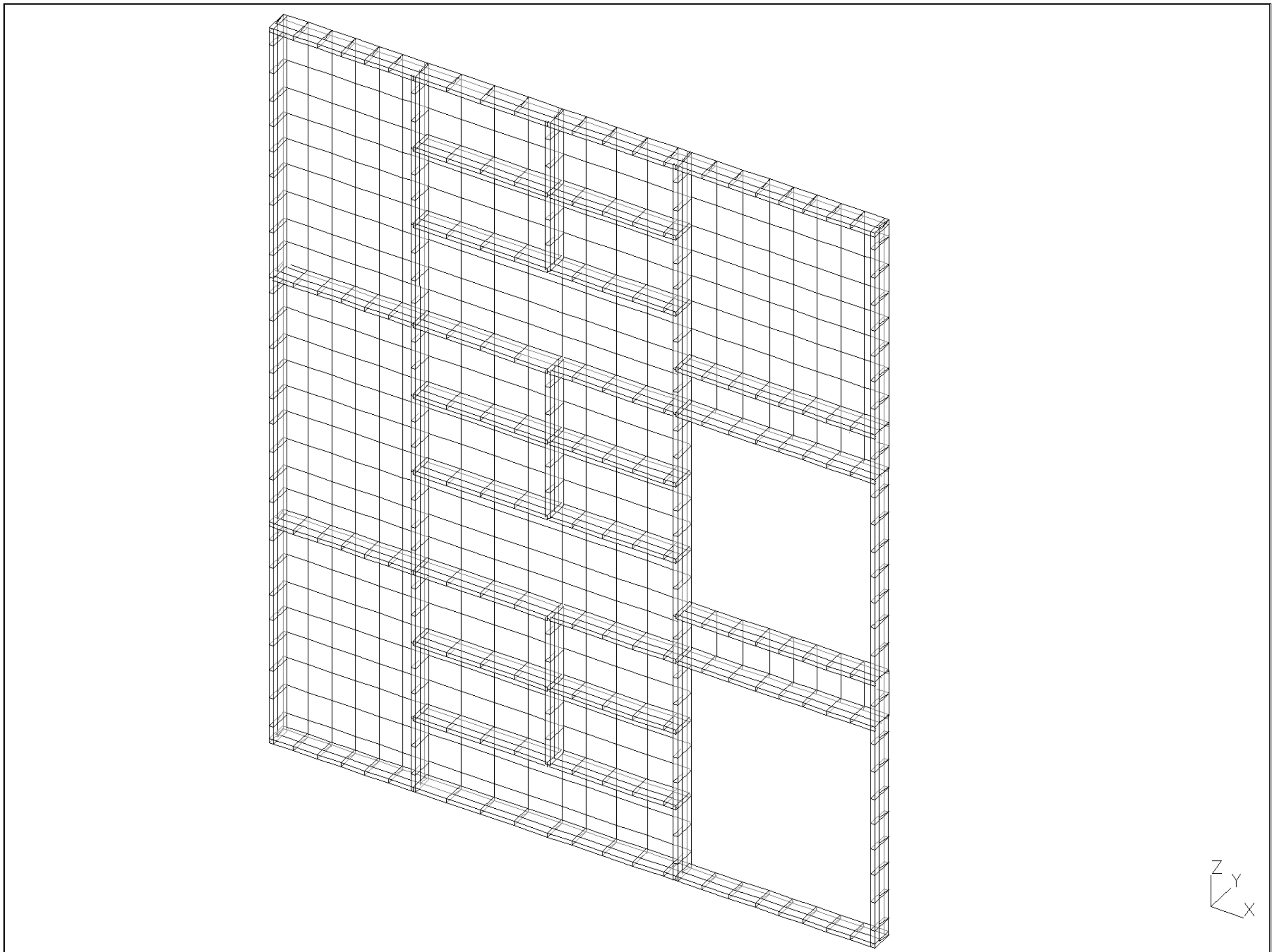


Figure 3-7 RC Rear Panel FEM

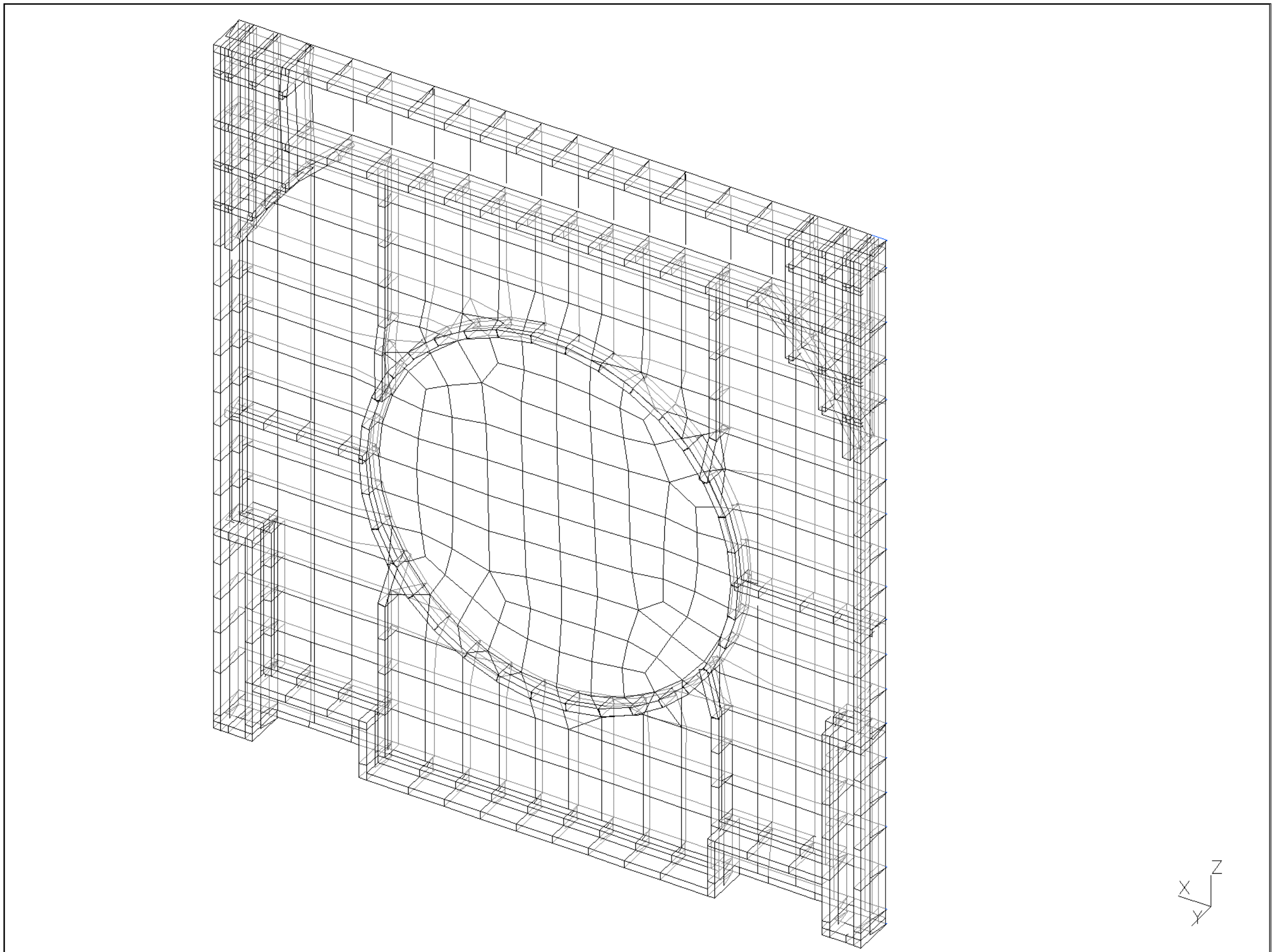


Figure 3-8 RC Front Door FEM

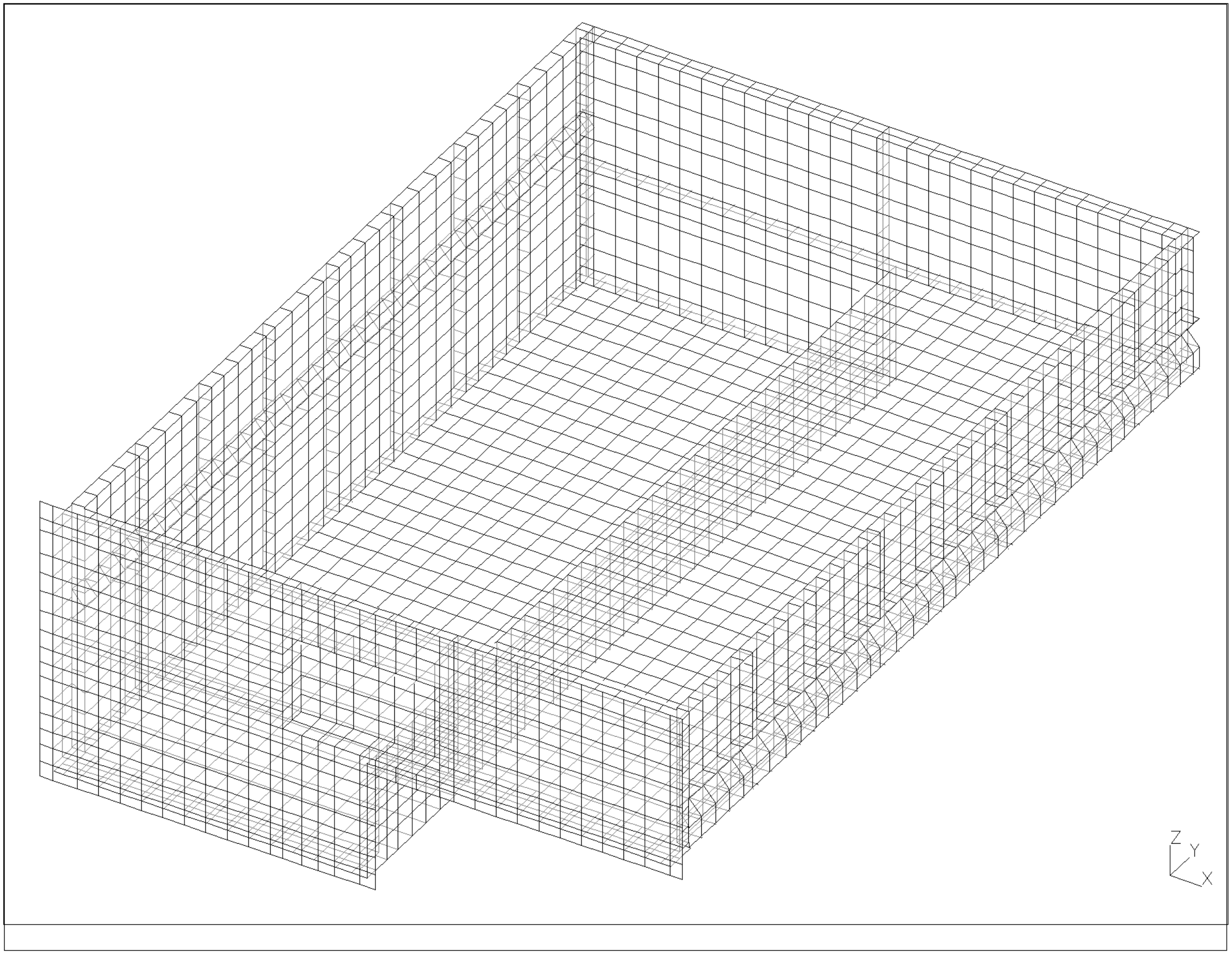


Figure 3-9 RC Stowage Drawer FEM

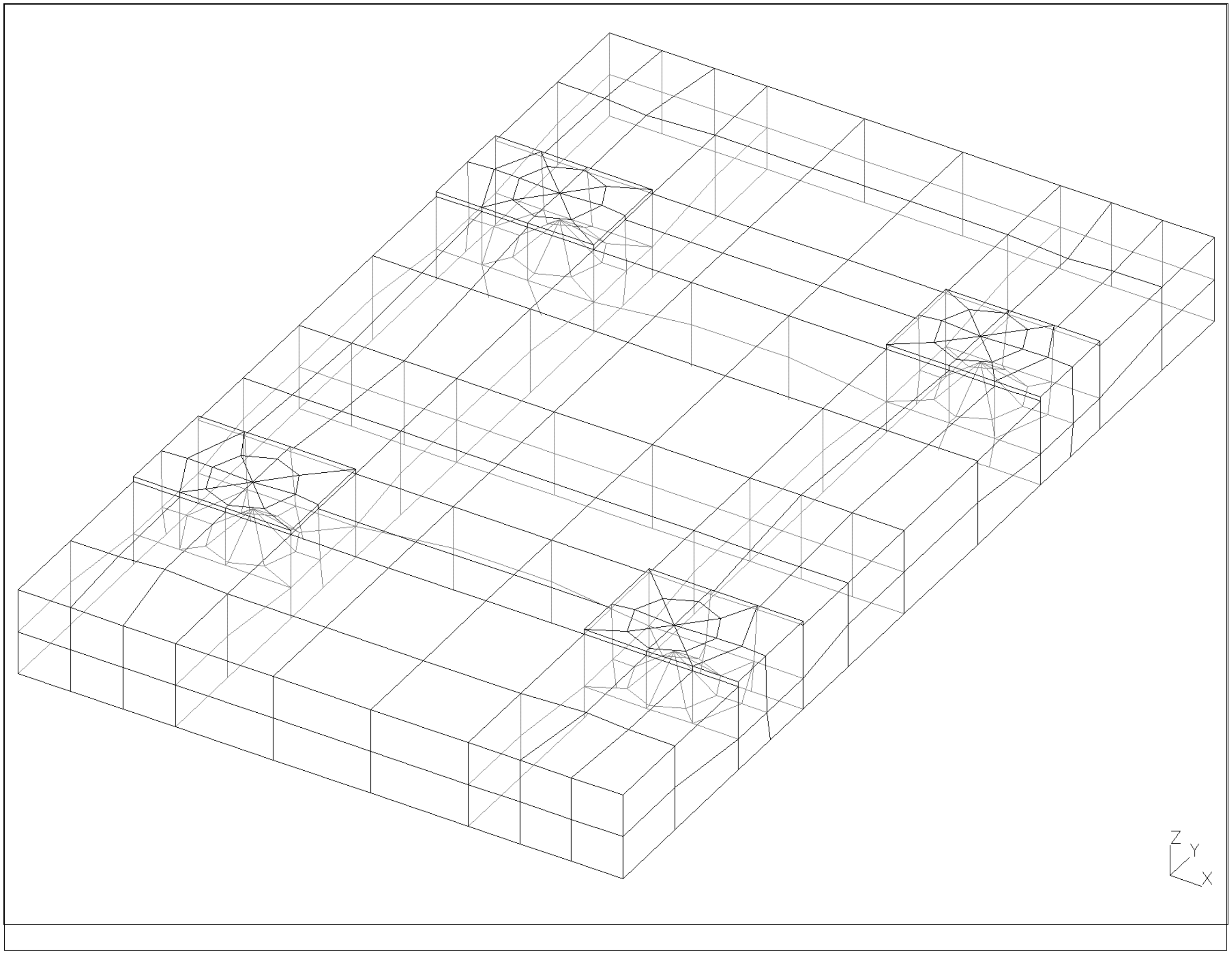


Figure 3-10 RC Floating Plate FEM

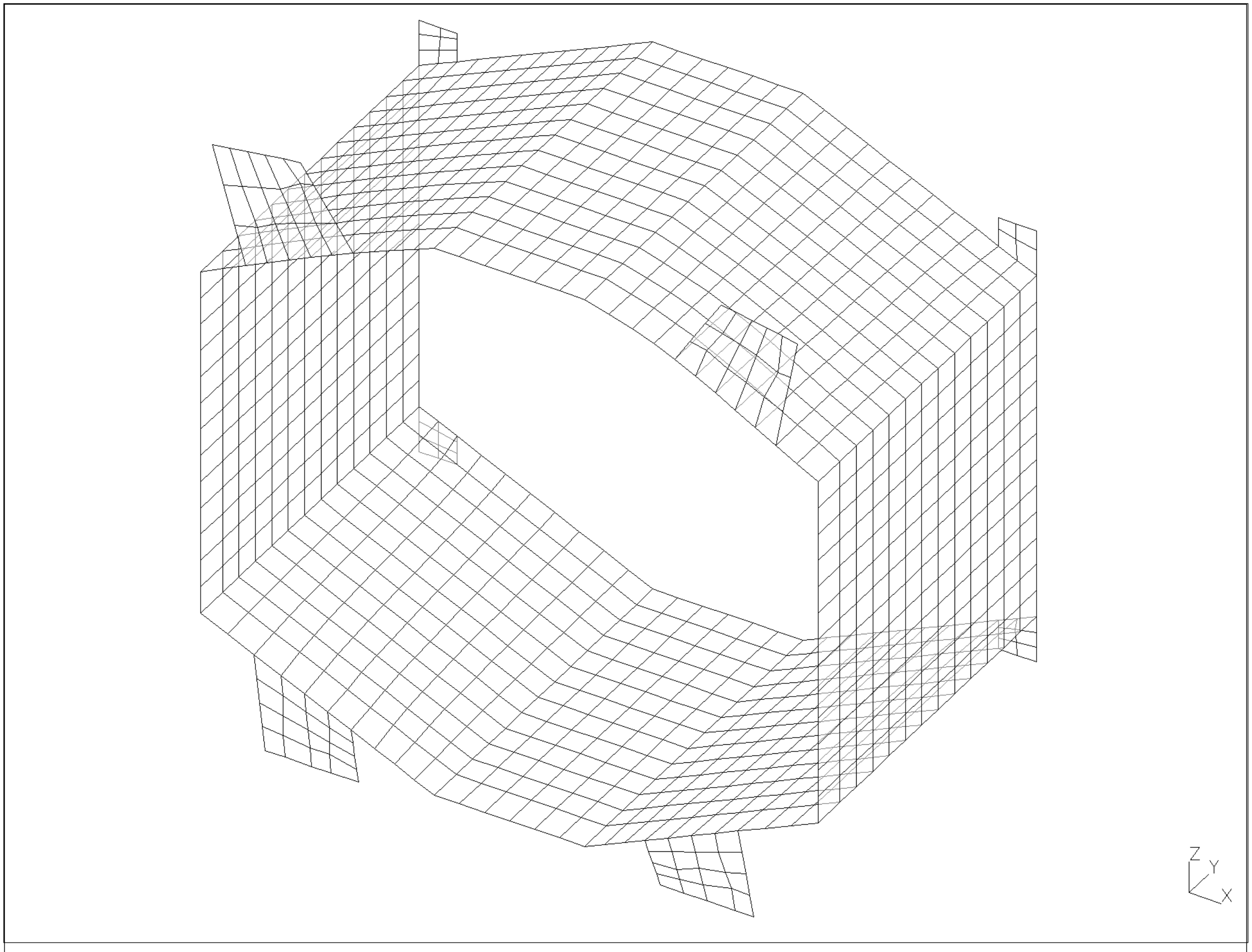


Figure 3-11 RC Centrifuge Assembly FEM

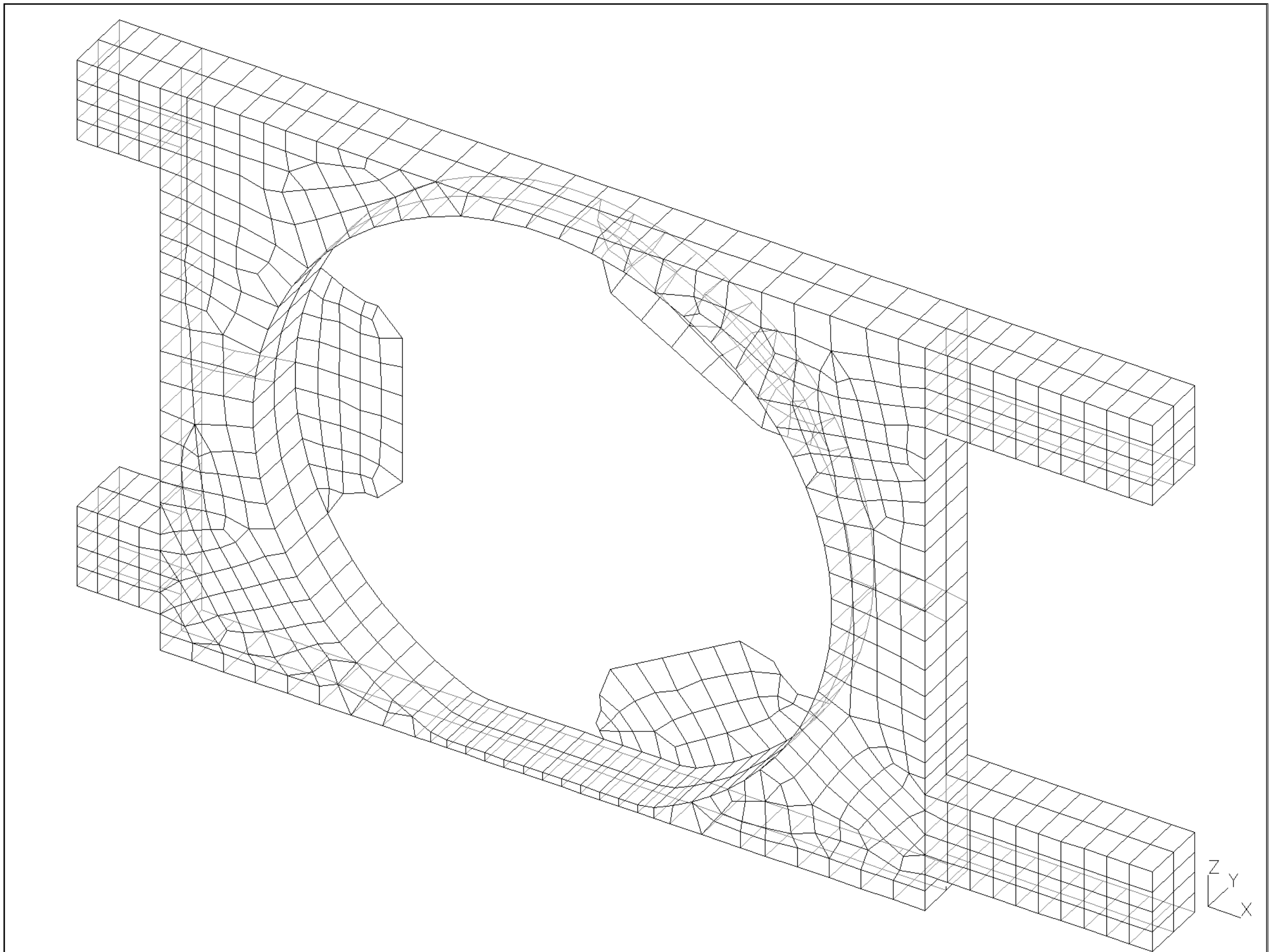


Figure 3-12 RC Support Assembly FEM

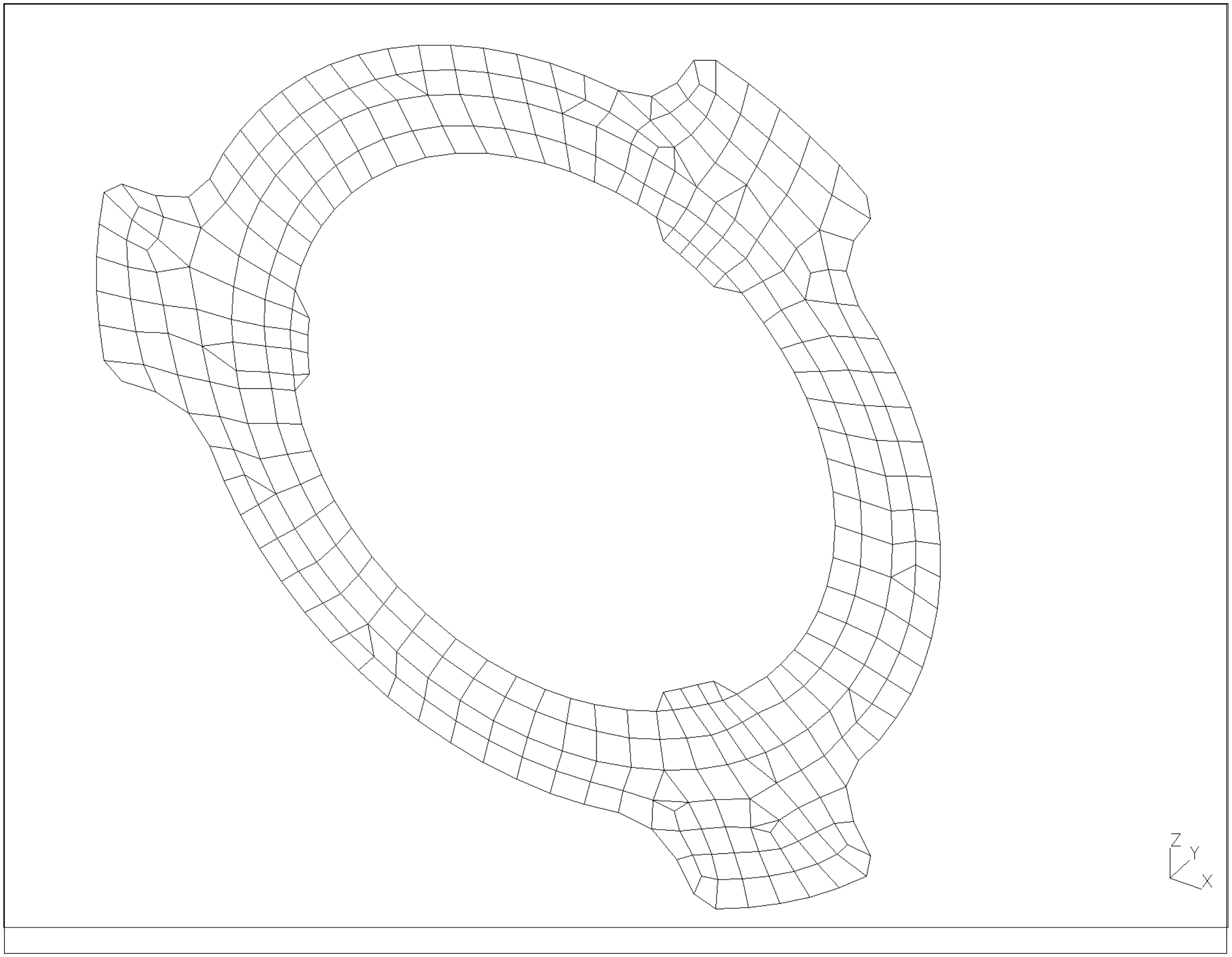


Figure 3-13 RC Motor Mounting Ring FEM

3.1 Model Verification

The model is checked for rigid body modes and for unit enforced displacements. Six rigid body mode frequencies of zero Hertz (Hz) (Table 3.5) indicate that the model is free of unintended constraints. The results of the unit load static analysis are checked for epsilon values of less than 10^{-6} (Table 3.7) and for unit enforced displacement (Table 3.6). The model is constrained at the end of the beam elements emulating the rack posts where the ends of the slide guides are attached. All the computed natural frequencies from a constrained dynamic analysis are more than 35 Hz (Table 3.8).

RC has a weight of 158.53 lb and a first mode frequency of 36.88 Hz. As per SSP 52005 Table 7.1-1, for a component weighs more than 70 lb and has a first mode frequency > 35 Hz and second mode frequency > 50 Hz, resonance search is required for the RC. A sine sweep test will be performed to verify the fundamental frequency of the drawer.

Table 3.2 Frequency Verification Requirements

EQUIPMENT ITEM	VERIFICATION
Wt < 40 lb (pounds) and $f_{1i} < 35$ Hz Wt < 40 lb and $f_{1i} > 35$ Hz	NASTRAN model with frequency identification up to 50 Hz in all directions by resonance search Analytical Model Only
$40 \leq$ Wt < 70 lb and $f_{1i} < 35$ Hz $40 \leq$ Wt < 70 lb and $f_{1i} \geq 35$ Hz	NASTRAN model verified by Model Survey up to 50 Hz NASTRAN model with frequency identification up to 50 Hz in all directions by resonance search
Wt $\geq$ 70 lb and $f_{1i} < 35$ Hz Wt $\geq$ 70 lb and $f_{1i} \geq 35$ Hz and $f_{2i} < 50$ Hz Wt $\geq$ 70 lb and $f_{1i} \geq 35$ Hz and $f_{2i} \geq 50$ Hz	NASTRAN model verified by Model Survey up to 50 Hz NASTRAN model verified by Model Survey up to 50 Hz NASTRAN model with frequency identification up to 50 Hz in all directions by resonance search

f_{1i} = the first (lowest) system eigen frequency in each direction (where: i = X, Y, Z direction)

f_{2i} = the second (or next highest)system eigen frequency in each direction (where: i = X, Y, Z direction)

Wt = includes weight of support structures and all supported components

Table 3.3 Grid Point Weight Generator Check

```
1  REFRIGERATED CENTRIFUGE                                                   SEP. 21, 2000  CSA/NASTRAN     HP        9/30/97  PAGE      9
   P/N SEG46117400-301                                                            MATRIX PROCESSING FOR SUPERELEMENT         0 (RESIDUAL )

                        O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
0                                                    REFERENCE POINT =        0


                                    MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM
                      ***                                                                                  ***
                      *  1.585320E+02   .000000E+00   .000000E+00   .000000E+00  8.798487E+03  2.365923E+03 *
                      *   .000000E+00  1.585320E+02   .000000E+00 -8.798487E+03   .000000E+00  4.605451E+03 *
                      *   .000000E+00   .000000E+00  1.585320E+02 -2.365923E+03 -4.605451E+03   .000000E+00 *
                      *   .000000E+00 -8.798487E+03 -2.365923E+03  5.374083E+05  6.859581E+04 -2.558515E+05 *
                      *  8.798487E+03   .000000E+00 -4.605451E+03  6.859581E+04  6.321556E+05  1.318485E+05 *
                      *  2.365923E+03  4.605451E+03   .000000E+00 -2.558515E+05  1.318485E+05  1.816865E+05 *
                      ***                                                                                  ***
                                       S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION
                                          ***                                         ***
                                          *  1.000000E+00   .000000E+00   .000000E+00 *
                                          *   .000000E+00  1.000000E+00   .000000E+00 *
                                          *   .000000E+00   .000000E+00  1.000000E+00 *
                                          ***                                         ***
                            DIRECTION
                        MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
                                X            1.585319E+02       .000000E+00 -1.492396E+01  5.549981E+01
                                Y            1.585320E+02      2.905062E+01   .000000E+00  5.549977E+01
                                Z            1.585320E+02      2.905062E+01 -1.492395E+01   .000000E+00
0                                                  I(S) - INERTIAS RELATIVE TO C.G.
                                          ***                                         ***
                                          *  1.378535E+04  1.357006E+02  2.500791E+02 *
                                          *  1.357006E+02  1.005005E+04 -5.402191E+02 *
                                          *  2.500791E+02 -5.402191E+02  1.258635E+04 *
                                          ***                                         ***
                                                     I(Q) - PRINCIPAL INERTIAS
                                          ***                                         ***
                                          *  1.385126E+04                             *
                                          *                1.263251E+04               *
                                          *                              9.937977E+03 *
                                          ***                                         ***
                                                     Q - TRANSFORMATION MATRIX
                                                        I(Q) = QT*IBAR(S)*Q
```

```
***                                         ***
*  9.731184E-01 -2.292804E-01  2.170569E-02 *
* -6.609402E-02 -1.877435E-01  9.799918E-01 *
* -2.206178E-01 -9.550827E-01 -1.978507E-01 *
***                                         ***
```

Table 3.4 Grid Point Weight Generator Check with Slide Guides and Rack Post Sections

```
1 REFRIGERATED CENTRIFUGE                                                      SEP. 21, 2000  CSA/NASTRAN     HP        9/30/97  PAGE     14
  P/N SEG46117400-301                                                               MATRICES AND LOADS FOR SUPERELEMENT        0 (RESIDUAL )

                           O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
0                                                      REFERENCE POINT =       0


                                     MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM
                      ***                                                                                  ***
                      *  2.194825E+02   .000000E+00   .000000E+00   .000000E+00  1.237789E+04  2.842681E+03 *
                      *   .000000E+00  2.194825E+02   .000000E+00 -1.237789E+04   .000000E+00  6.526583E+03 *
                      *   .000000E+00   .000000E+00  2.194825E+02 -2.842681E+03 -6.526583E+03   .000000E+00 *
                      *   .000000E+00 -1.237789E+04 -2.842681E+03  7.608356E+05  8.396046E+04 -3.684455E+05 *
                      *  1.237789E+04   .000000E+00 -6.526583E+03  8.396046E+04  9.096621E+05  1.597224E+05 *
                      *  2.842681E+03  6.526583E+03   .000000E+00 -3.684455E+05  1.597224E+05  2.572839E+05 *
                      ***                                                                                  ***
                                        S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION
                                           ***                                         ***
                                           *  1.000000E+00   .000000E+00   .000000E+00 *
                                           *   .000000E+00  1.000000E+00   .000000E+00 *
                                           *   .000000E+00   .000000E+00  1.000000E+00 *
                                           ***                                         ***
                            DIRECTION
                        MASS AXIS SYSTEM (S)      MASS             X-C.G.        Y-C.G.        Z-C.G.
                                X            2.194824E+02       .000000E+00 -1.295175E+01  5.639581E+01
                                Y            2.194825E+02      2.973624E+01   .000000E+00  5.639580E+01
                                Z            2.194825E+02      2.973624E+01 -1.295175E+01   .000000E+00
0                                                 I(S) - INERTIAS RELATIVE TO C.G.
                                           ***                                         ***
                                           *  2.595694E+04  5.701901E+02  3.735763E+02 *
                                           *  5.701901E+02  1.752489E+04  5.929120E+02 *
                                           *  3.735763E+02  5.929120E+02  2.639019E+04 *
                                           ***                                         ***
                                                      I(Q) - PRINCIPAL INERTIAS
                                           ***                                         ***
                                           *  1.744394E+04                             *
                                           *                2.581640E+04               *
                                           *                              2.661167E+04 *
                                           ***                                         ***
                                                      Q - TRANSFORMATION MATRIX
                                                         I(Q) = QT*IBAR(S)*Q
```

Prepared By	Shaji Ommen	LOCKHEED MARTIN SPACE OPERATIONS *Mechanical Systems Analysis Department*	Date 9 – 25 – 00	File Name
Checked By	D. Van		Drawing No. [redacted]	
Title	Refrigerated Centrifuge (RC) Stress Analysis Report		Report No. LMSEAT 33513	

```
***                                        ***
*  6.967862E-02  8.759504E-01  4.773425E-01 *
*  9.951896E-01 -9.407070E-02  2.735526E-02 *
*  6.886579E-02  4.731402E-01 -8.782914E-01 *
  ***                                        ***
```

Table 3.5 Rigid Body Modes Check

```
1  REFRIGERATED CENTRIFUGE                                            SEP. 21, 2000  CSA/NASTRAN     HP        9/30/97  PAGE     27
                                                                                                              SUPERELEMENT SOLUTION
0    UNCONSTRAINED CENTRIFUGE MODES

                                             R E A L   E I G E N V A L U E S
```

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIAN FREQUENCY	CYCLIC FREQUENCY	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	-3.538291E-07	5.948353E-04	9.467098E-05	2.745825E-01	-9.715528E-08
2	2	1.963685E-07	4.431349E-04	7.052711E-05	1.960119E-01	3.849057E-08
3	3	3.800353E-07	6.164700E-04	9.811424E-05	3.105148E-01	1.180066E-07
4	4	7.829635E-07	8.848523E-04	1.408286E-04	3.736595E-01	2.925618E-07
5	5	1.114648E-06	1.055769E-03	1.680308E-04	2.339983E-01	2.608257E-07
6	6	1.742588E-06	1.320071E-03	2.100958E-04	1.424356E-01	2.482065E-07
7	7	1.245575E+04	1.116053E+02	1.776254E+01	5.933608E-02	7.390754E+02
8	8	1.257308E+04	1.121297E+02	1.784600E+01	4.456984E-02	5.603801E+02
9	9	1.304142E+04	1.141991E+02	1.817534E+01	3.652295E-02	4.763113E+02
10	10	5.981653E+04	2.445742E+02	3.892519E+01	1.022831E-01	6.118218E+03
11	11	1.561752E+05	3.951901E+02	6.289645E+01	8.247630E-02	1.288075E+04
12	12	1.881280E+05	4.337372E+02	6.903141E+01	1.663161E-02	3.128871E+03
13	13	2.236495E+05	4.729159E+02	7.526691E+01	2.351754E-03	5.259684E+02
14	14	2.360420E+05	4.858415E+02	7.732407E+01	9.906363E-02	2.338317E+04
15	15	2.848308E+05	5.336954E+02	8.494025E+01	1.757484E-02	5.005854E+03

```
0*** USER INFORMATION MESSAGE, SUPERELEMENT SOLUTION OPERATIONS COMPLETED
```

Table 3.6 Unit Enforced Displacement Check

```
1 REFRIGERATED CENTRIFUGE                                    JUN. 20, 2000  CSA/NASTRAN     HP       9/30/97  PAGE    200
  UNIT ENFORCEMENT CHECK                                               DATA RECOVERY FOR SUPERELEMENT        0 (RESIDUAL )
                                                  M A X / M I N   S U M M A R Y
```

	SUBCASE	TYPE	T1	T2	T3	R1	R2	R3
DISPLACEMENTS	10001	GRID	20001	36190	32740	38932	39229	38932
		MAX	1.000000E+00	3.361727E-12	2.721415E-12	8.733950E-09	3.786600E-10	1.908008E-08
		GRID	20000	32727	32583	38316	39202	38959
		MIN	.000000E+00	-2.082445E-12	-2.480524E-12	-7.728954E-09	-7.031442E-11	-8.556551E-09
DISPLACEMENTS	10002	GRID	20621	20001	20246	20246	39206	38437
		MAX	4.866796E-10	1.000000E+00	3.335605E-11	8.973272E-09	8.004832E-10	2.391980E-09
		GRID	41032	20000	41033	20241	39229	20247
		MIN	-1.107830E-09	.000000E+00	-1.746675E-08	-3.878351E-09	-1.121045E-09	-2.818432E-09
DISPLACEMENTS	10003	GRID	20623	20236	20001	38658	39206	38310
		MAX	1.479741E-09	3.410478E-09	1.000000E+00	6.080140E-09	1.033351E-09	2.307010E-08
		GRID	48112	20240	20000	20251	36463	38963
		MIN	-1.695290E-09	-6.210397E-09	.000000E+00	-1.904126E-08	-2.479851E-09	-2.355401E-08
DISPLACEMENTS	10004	GRID	26194	20029	22118	38956	39229	38956
		MAX	1.814724E-08	7.946999E-01	1.159900E+00	1.000150E-01	1.467823E-05	3.284666E-05
		GRID	25191	20405	48112	20000	39206	38932
		MIN	-2.006972E-08	-1.302300E+00	-1.454400E+00	.000000E+00	-1.311222E-05	-5.888680E-05
DISPLACEMENTS	10005	GRID	20405	39194	20027	39203	39192	39089
		MAX	1.302300E+00	1.382437E-07	8.963001E-01	2.307978E-03	1.001368E-01	4.973164E-05
		GRID	20026	20006	20026	39190	20000	39187
		MIN	-7.946998E-01	-4.136267E-07	-1.003700E+00	-3.278626E-03	.000000E+00	-8.847052E-03

```
DISPLACEMENTS     10006  GRID       41031           20026           38067           38650           38178           38437
                         MAX   1.454400E+00    1.003700E+00    1.260818E-06    4.581498E-02    7.762539E-05    1.077886E-01

                         GRID       22118           20027           38057           38923           22287           20000
                         MIN  -1.159900E+00   -8.963001E-01   -9.415703E-07   -4.578590E-02   -5.439183E-04    .000000E+00
```

Table 3.7 Epsilon Check

```
1 REFRIGERATED CENTRIFUGE                                               SEP. 21, 2000  CSA/NASTRAN     HP        9/30/97  PAGE   1901
  P/N SEG46117400-301                                                             DATA RECOVERY FOR SUPERELEMENT        0 (RESIDUAL )
0     STATIC RUN

0   LOAD SEQ. NO.             EPSILON             STRAIN ENERGY     EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS.
                1         -1.3125037E-12         1.3094048E+02
                2         -1.5214652E-12         1.2875581E+02
                3         -8.6194512E-13         1.3402071E+02
                4         -1.1127787E-12         1.3927173E+02
                5         -7.3740997E-13         1.1276959E+02
                6         -6.4096813E-13         1.0789651E+02
                7         -1.2035185E-12         1.0392945E+02
                8         -3.4412702E-13         1.0649205E+02
                9         -2.9673396E-13         1.0284561E+02
               10         -7.6540581E-13         9.9873466E+01
               11         -4.3825154E-13         1.0346413E+02
               12          3.0821374E-14         1.0837638E+02
               13          3.0821374E-14         1.0837638E+02
               14         -4.3825154E-13         1.0346413E+02
               15         -7.6540581E-13         9.9873466E+01
               16         -2.9673396E-13         1.0284561E+02
               17         -2.9363008E-13         9.9869972E+01
               18         -7.2884515E-13         9.6994499E+01
               19         -1.9862036E-13         1.0028055E+02
               20         -1.0821613E-12         1.0518626E+02
```

21	-1.0821613E-12	1.0518626E+02
22	-1.9862036E-13	1.0028055E+02
23	-7.2884515E-13	9.6994499E+01
24	-2.9363008E-13	9.9869972E+01

0*** USER INFORMATION MESSAGE, SUPERELEMENT SOLUTION OPERATIONS COMPLETED

Table 3.8 Natural Frequency Check

1 SEP. 21, 2000 CSA/NASTRAN HP 9/30/97 PAGE 27

SUPERELEMENT SOLUTION

0 CONSTRAINED CENTRIFUGE MODES

R E A L E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIAN FREQUENCY	CYCLIC FREQUENCY	GENERALIZED MASS	GENERALIZED STIFFNESS
1*	1	1.119103E+04	1.057877E+02	1.683663E+01	2.643104E-02	2.957906E+02
2*	2	1.155054E+04	1.074734E+02	1.710493E+01	2.609456E-02	3.014062E+02
3*	3	1.225235E+04	1.106903E+02	1.761691E+01	2.631498E-02	3.224203E+02
4	4	5.370152E+04	2.317359E+02	**3.688191E+01**	8.602525E-02	4.619687E+03
5	5	1.228353E+05	3.504787E+02	5.578041E+01	1.111914E-01	1.365823E+04
6	6	1.289201E+05	3.590545E+02	5.714530E+01	1.684584E-01	2.171769E+04
7	7	1.846799E+05	4.297440E+02	6.839588E+01	1.541655E-02	2.847127E+03
8	8	2.216716E+05	4.708202E+02	7.493336E+01	2.390451E-03	5.298951E+02
9	9	2.333099E+05	4.830216E+02	7.687527E+01	1.501180E-02	3.502402E+03
10	10	3.176778E+05	5.636292E+02	8.970436E+01	5.669596E-03	1.801105E+03
11	11	3.213505E+05	5.668778E+02	9.022141E+01	1.542995E-04	4.958422E+01
12	12	3.238950E+05	5.691177E+02	9.057790E+01	1.599489E-03	5.180664E+02
13	13	3.381544E+05	5.815105E+02	9.255027E+01	1.790128E-03	6.053398E+02
14	14	4.100639E+05	6.403623E+02	1.019168E+02	4.794226E-03	1.965939E+03

```
      15         15       4.573009E+05       6.762402E+02       1.076270E+02       4.278865E-03       1.956729E+03
0*** USER INFORMATION MESSAGE, SUPERELEMENT SOLUTION OPERATIONS COMPLETED
```

* Modes 1-3 are Related to Stowage Mass

4.0 DESIGN LOADS REQUIREMENTS

This section describes the design loads requirements and gives the guidelines for their calculation and use in stress analysis. The loads criteria are usually given in terms of accelerations (expressed in g's) pertaining to each phase of flight operations and/or carriers. A load factor is equal in magnitude and opposite in direction from an acceleration. All combinations of accelerations corresponding to a given mission phase shall be applied to obtain limit loads for that mission phase. The design loads are defined as the largest of the combined loads that apply during a mission phase. Specific rules for combination are described in the following section.

4.1 Loads Definition

The RC will be flown in HRF Rack 2 in MPLM. The loads are a combination of quasi-static and random vibration loads. This section provides the quasi-static loads, calculation of random vibration loads and the combination of loads for the RC.

4.1.1 Quasi-Static Loads

Quasi-static load factors from Table 4.1will are used in the load combination specified in Section 4.1.3. The load factors are in the RC coordinate system.

Table 4.1 ISPR Mounted Component Load Factors

Event	Nx (g)	Ny (g)	Nz (g)
Liftoff	± 7.7	± 11.6	± 9.9
Landing	± 5.4	± 7.7	± 8.8

SSP 57000, Rev. D, Table 3.1.1.3-4

4.1.2 Random Vibration Loads

The random vibration loads acting on payload flight equipment result from the structural response of the equipment component to induce random disturbances from the propulsion system during launch. These high frequency disturbances result in both mechanical and acoustic borne excitation, and occur during the launch phase only (lift-off and ascent) while the main engines are operating.

In order to assess random vibration loads in hardware analysis, several simplifying assumptions must be made. Equivalent static load factors are generally calculated in each axis so they may be combined with low frequency load factors and used in structural analysis. Random Vibration Load Factors (RVLF) for the RC are generated from high-frequency random vibration

4.1.2 Random Vibration Loads *Continued*

environment data listed in Tables 4.2. RVLF is calculated using the modal mass participation method explained in SSP 52005, Rev. B, Appendix C.

Table 4.2 Random Vibration Environment for ISPR Post-Mounted Equipment Weighing More than 100 Pounds in the MPLM

Frequency (Hz)	PSD (g^2/Hz) or Slope (dB/octave)
20	0.002 g^2/Hz
20 - 70	+4.8 dB/octave
70-200	0.015 g^2 /Hz
200 - 2000	-3.7 dB/octave
2000	0.0006 g^2/Hz
Composite	2.4 g_{rms}

SSP 57000, Rev. D, Table 3.1.1.3-3

From the constraint run all the modes from 0 to 2000 Hz are chosen. The Power Spectral Density (PSD) values are calculated for these 741 modes. If the frequency of interest (f_n) falls on either a positive or negative slope of the input spectrum, the following equation is used to interpolate for the PSD_n value:

$$PSD_n = PSD_1\left(\frac{f_n}{f_1}\right)^{0.3322*S}$$

Where,

f_1 = Reference frequency (at start of slope)
f_n = Frequency of interest
S = Slope of the PSD curve at frequencies above f_1 (dB/octave)
PSD_1 = Power Spectral Density at f_1

RVLF are typically calculated from the applicable random vibration criteria using Miles' Equation, which is based upon statistical analyses of induced acceleration spectra with a 3-sigma distribution.

4.1.2 Random Vibration Loads *Continued*

$$RVLF_n = 3 * \sqrt{\frac{\pi}{2} * Q * f_n * PSD_n}$$

Where,

f_n = Natural frequency (n = x, y, z)
Q = Amplification factor
PSD_n = Random vibration environment Power Spectral Density at f_n (n = x, y, z)

Amplification factor (Q) is chosen based on component mass, support structure flexibility, and method of attachment. For most components, a Q of 10 for all three directions should be used if no test data are available.

Then $RVLF_{nrms}$ = $Effectivemass_n * RVLF_n$

The mean value of the random vibration load factor is calculated as

$$RVLF_{nmw} = RVLF_{nrms} / M$$

where, M is the total mass of the component.

RVLF in each axis (R_n)is calculated by taking square root of the sum of the squares of the $RVLF_{nmw}$ in that axis. By averaging the load factors in this manner, system modes dominate but all modes contribute to the outcome.

4.1.3 Load Combinations

For Liftoff, quasi-static load factors must be combined with the random vibration load factors. Quasi-static and random vibration load factors are combined to form 24 load cases. If R_x, R_y and R_z are the random load factors, then the combined load factors, C_x, C_y and C_z can be developed as defined in SSP 52005, Rev. B, Table 4.1.2-1 (Root Sum Square Method):

$$C_x = 1.5 \pm [(N_x - 1.5)^2 + R_x^2]^{0.5}$$

$$C_y = \pm [N_y^2 + R_y^2]^{0.5}$$

$$C_z = \pm [N_z^2 + R_z^2]^{0.5}$$

4.1.3 Load Combinations *Continued*

The combined quasi-static and random vibration load factors are the design load factors for the RC and are shown in the following table. Only the launch load factors are considered since the launch load factors enveloped the landing load factors.

Table 4.3 RC Design Load Factors

Load	Load Factors		
Case	X	Y	Z
1	12.17	11.60	9.90
2	12.17	11.60	-9.90
3	12.17	-11.60	9.90
4	12.17	-11.60	-9.90
5	-9.17	11.60	9.90
6	-9.17	11.60	-9.90
7	-9.17	-11.60	9.90
8	-9.17	-11.60	-9.90
9	7.70	10.25	9.90
10	7.70	10.25	-9.90
11	7.70	-10.25	9.90
12	7.70	-10.25	-9.90
13	-7.70	10.25	9.90
14	-7.70	10.25	-9.90
15	-7.70	-10.25	9.90
16	-7.70	-10.25	-9.90
17	7.70	11.60	10.36
18	7.70	11.60	-10.36
19	7.70	-11.60	10.36
20	7.70	-11.60	-10.36
21	-7.70	11.60	10.36
22	-7.70	11.60	-10.36
23	-7.70	-11.60	10.36
24	-7.70	-11.60	-10.36

4.2 Crew-Induced Loads

Design load factors associated with crew applied loads for payloads installed in habitable areas or payloads susceptible to crew applied loads are defined in 57000, Rev. D, Table 3.1.1.3-1.

Table 4.4 Crew Induced Loads

CREW SYSTEM OR STRUCTURE	TYPE OF LOAD	LOAD	DIRECTION OF LOAD
Levers, Handles, Operating Wheels, Controls	Push or Pull concentrated on most extreme edge	222.6 N (50 lbf), limit	Any Direction
Small Knobs	Twist (torsion)	14.9 N-m (11 ft-lbf), limit	Either direction
Exposed Utility Lines (Gas, Fluid, and Vacuum)	Push or Pull	222.6 N (50 lbf)	Any Direction
Cabinets and any normally exposed equipment	Load distributed over a 4 inch by 4 inch area	556.4 N (125 lbf), limit	Any Direction
Legend: ft = feet, m = meter, N = Newton, N-m = Newton meter, lbf = pounds force			

SSP 57000, Rev. D, Table 3.1.1.3

5.0 DETAILED ANALYSIS

The effects of the combined quasi-static and random loads for 24 load cases on the RC are analyzed with CSA/NASTRAN software. The bar element forces are then used to calculate stresses and margins of safety using a customized Formula Translator (FORTRAN) program.

5.1 Plate Element Analysis

The highest principal and von Mises stresses for plate elements in the RC Assembly are sorted by a customized a FORTRAN program. Maximum von Mises stress is used to calculate the yield margin of safety and maximum principal stress is used to calculate the ultimate margin of safety.

The smallest margin occurs in the front panel, which is made of 7075-T7351 Aluminum alloy per QQ-A-250/12. Maximum principal stress is 30583.07 psi for load cases 104 and the maximum von Mises stress is 27769.58 psi for the same load cases (Table 5.5) on Element #20494.
Von Mises stresses are based on:

$$\text{von Mises stress, } \sigma_v = \sqrt{s_1^{\,2} - s_1 * s_2 + s_2^{\,2}}$$

where,

s_1, s_2 = principal stresses

$$\sigma_v = \sqrt{-30583.07^2 - (-30583.075 * -6945.50) + -6945.50^2}$$

σ_v = 27769.07 psi

The margin of safety is then calculated using the equation:

$$MS_u = \frac{F_{tu}}{FS_u * s_1} - 1$$

$$MS_y = \frac{F_{ty}}{FS_y * \sigma_v} - 1$$

where,

F_{tu} = ultimate allowable stress

F_{ty} = yield allowable stress

5.1 Plate Element Analysis *Concluded*

FS_u = ultimate factor of safety, 2.0

FS_y = yield factor of safety, 1.25

The margin of safety calculations are as follows:

F_{tu} = 68000 psi

F_{ty} = 57000 psi

$$MS_u = \frac{68000}{2.0 * 30583.07} - 1 = 0.112$$

$$MS_y = \frac{57000}{1.25 * 27769.58} - 1 = 0.642$$

5.2 Beam Element Analysis

Beam members, such as panel stiffeners, and slides are modeled as CBAR elements in the RC FEM. The ultimate margin of safety for beam members is computed based on the maximum principal stress and yield margin of safety is computed based on von Mises stress for each member.

The von Mises stresses are computed by a customized FORTRAN program. The following explains the algorithm used in the derivation of von Mises stress for beam members.

von Mises Stress Computation

The FORTRAN program reads the bar element forces from CSA/NASTRAN and calculates the stresses of a bar based on its cross sectional properties. The loads applied to the cross section are the axial load, P_a, two shears, V_1 and V_2, two bending moments, M_1 and M_2, and torque, T, recovered from the CSA/NASTRAN bar element force results.

Considering first the axial load and the bending moments, the maximum tensile or compressive stresses will occur at one of the four corners and is a combination of the stress due to P_a, M_1, and M_2. The general equation used to calculate the maximum stress is:

$$\sigma_L = \frac{P_a}{A} + \frac{M_1 c_1}{I_1} + \frac{M_2 c_2}{I_2}$$

Where,

σ_L = Calculated tensile or compressive stress

A = cross sectional area of the structural member

c_i = Maximum fiber distance from the i-axis

I_i = Moment of inertia about the i-plane

Two shear forces, V_1 and V_2, and torque, T, produce shear stresses on the outside fiber of the cross section of the structural member. The equation used to compute shear stress is:

$$t_{xy} = \frac{T_{total}}{q} + \frac{V_1 Q_1}{I_1 b_1} + \frac{V_2 Q_2}{I_2 b_2}$$

5.2 Beam Element Analysis *Continued*

Where,

t_{xy} = Calculated shear stress

Q_i = First moment of the area of the beam from the neutral axis in the i-direction

= A'z' where A' is the area above or below the neutral axis and z' is the centroid of A' measured from the neutral axis

b_i = Thickness of the beam in the i-direction

q = Constant relating torque to shear (Reference 16, page 348)

I_i = Moment of inertia about the i-plane

$T_{total} = T + V_1 * c_{coff2} + V_2 * c_{coff1}$

(Takes into account the fact that the shear center and the centroid of the beam do not always occur at the same location)

To compute the shear stress from torque, use a conservative rectangular area that fits inside the cross section.

$$1/q = \frac{3}{8ab^2}\left[1 + 0.6095\frac{b}{a} + 0.8865\left(\frac{b}{a}\right)^2 - 1.8023\left(\frac{b}{a}\right)^3 + 0.91\left(\frac{b}{a}\right)^4\right]$$

Where,

a = half of the long side of the rectangle
b = half of the short side of the rectangle

The von Mises stresses are calculated by first computing the principal stresses as follows:

$$s_1, s_2 = \frac{1}{2}\sigma_L \pm \sqrt{\frac{1}{4}\sigma_L^2 + t_{xy}^2}$$

and subsequently calculating the von Mises stresses,

5.2 Beam Element Analysis *Continued*

$$f_v = \sqrt{s_1^2 + s_2^2 - s_1 * s_2}$$

The margins of safety are then calculated from the equations:

$$MS_y = \frac{F_y}{1.25 * f_v} - 1$$

$$MS_u = \frac{F_u}{2.0 * s_1} - 1$$

Where F_y and F_u are the yield and ultimate stress allowable (or the modulus of rupture as required) for the beam material.

Sample Calculation to Confirm the Results of FORTRAN program

The bottom panel 0.75 x 0.225 stiffener (element #23935) is used for demonstration.

The cross sectional properties of the stiffener are listed below.

$A = 0.169\ in^2$

$I_1 = I_x = 0.0007119\ in^4$

$I_2 = I_y = 0.00791\ in^4$

$c_1 = y_{cg} = 0.1125\ in$

$c_2 = x_{cg} = 0.375\ in$

$b_1 = 0.75\ in$

$b_2 = 0.225\ in$

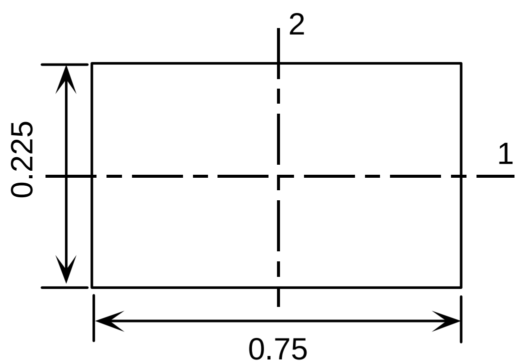


Figure 5-12 Stiffener Cross Section

$Q_1 = A_{bottom} * z_1' = 0.084 * 0.056 = 0.00475\ in^3$

$Q_2 \quad = A_{left} * z_2' = 0.084 * 0.1875 = 0.0158 \text{ in}^3$

5.2 Beam Element Analysis *Continued*

$$\frac{Q_1}{I_1\, b_1} = \frac{0.00475}{0.0007119 * 0.75} = 8.889 \text{ in}^{-2}$$

$$\frac{Q_2}{I_2\, b_2} = \frac{0.0158}{0.00791 * 0.225} = 8.889 \text{ in}^{-2}$$

$$1/q = \frac{3}{8ab^2}\left[1 + 0.6095\frac{b}{a} + 0.8865\left(\frac{b}{a}\right)^2 - 1.8023\left(\frac{b}{a}\right)^3 + 0.91\left(\frac{b}{a}\right)^4\right]$$

Where, a = 0.375 & b = 0.1125

$q \quad = 0.0104$

Yield = 57000 psi

Ultimate = 68000 psi

$C_{off2} = C_{off1} = 0.0$ in

The load applied to stiffener is pulled from the CSA/NASTRAN output.

LOAD ID	BMA1	BMA2	BMB1	BMB2	SHEAR1	SHEAR2	AXIAL	TORQUE
102	-134.105	24.656	21.525	1.670	-180.128	26.604	980.222	6.439

Absolute values of these numbers will be used for conservatism.

$$\sigma = \frac{P_a}{A} + \left|\frac{M_1 c_1}{I_1}\right| + \left|\frac{M_2 c_2}{I_2}\right|$$

$$\sigma_A = \frac{980.222}{0.169} + \frac{134.105 * 0.1125}{0.0007119} + \frac{24.656 * 0.375}{0.00791} = 28161.350 \text{ psi}$$

$$\sigma_B = \frac{980.222}{0.169} + \frac{21.525 * 0.1125}{0.0007119} + \frac{1.67 * 0.375}{0.00791} = 9280.851 \text{ psi}$$

5.2 Beam Element Analysis *Concluded*

The maximum element bending stress is:

$$\sigma_{max} = \sigma_A = 28161.350 \text{ psi}$$

For the shear stress on the element:

$$t_{xy} = \frac{T}{q} + \left|\frac{V_1 Q_1}{I_1 b_1}\right| + \left|\frac{V_2 Q_2}{I_2 b_2}\right|$$

$$t_{xy} = 6.439 / 0.0104 + 180.128 * 8.889 + 26.604 * 8.889 = 2456.775 \text{ psi}$$

The principal stresses are as follows:

$$s_1, s_2 = \frac{1}{2}\sigma_{max} \pm \sqrt{\frac{1}{4}\sigma^2_{max} + t^2_{xy}}$$

$$s_1 = 28374.070 \text{ psi}$$

$$s_2 = -212.720 \text{ psi}$$

Subsequently, calculating the von Mises stresses:

$$f_v = [s_1^2 + s_2^2 - s_1 * s_2]^{1/2} = 28481.026 \text{ psi}$$

The margins of safety are then calculated using the ultimate and yield allowables.

$$MS_y = \frac{F_y}{1.25 * f_v} - 1 = \frac{57000}{1.25 * 28481.026} - 1 = 0.601$$

$$MS_u = \frac{F_u}{2.0 * s_1} - 1 = \frac{68000}{2.0 * 28374.07} - 1 = 0.198$$

The above margins of safety concur with the calculations of the FORTRAN program.

5.3 Fastener Analysis

Interface connection for the fastener-joints between parts are checked based on fastener strength and fastener hole bearing and shear tear-out strength. The fasteners and the fastener holes are checked for both yield and ultimate strength.

The panels are connected together by NAS1102-3 CRES A286 #10 screws. The stowage drawer panels are connected together by NAS1102-08 and NAS1101-08 CRES A286 #8 screws. The slides are connected to the side panels by NAS1101-3 CRES A286 #10 screws. Also the floating plate to the bottom panel and the motor mounting ring to the support assembly connections are by NAS 1351N4 heat-resistant steel ¼ inch fasteners. The MOS for tension, shear, bearing, and shear-tear-out will be computed by a customized FORTRAN program.

The fastener that experiences the lowest margin is a NAS1351N4 screw and is located on the floating plate to bottom panel connection: element 47602, load case 107. The MOS for this fastener will be verified for each failure condition. This MOS is obtained by computing heel-toe force and adding axial force and preload. Sample calculations for this worst-case fastener are shown below.

LOAD ID	BMA1	BMA2	BMB1	BMB2	SHEAR1	SHEAR2	AXIAL
107	-141.354	154.343	0.00	0.00	-161.547	176.392	316.849

Absolute values of these numbers will be used for conservatism.

Resultant Moment End A $= \sqrt{BMA1^2 + BMA2^2} = \sqrt{141.354^2 + 154.343^2} = 209.291$ in-lb

Heel-Toe Force $= \dfrac{M}{d_{head}/2} = \dfrac{209.291}{(0.375/2)} = 1116.219$lb

M = Moment

d_{head} = Bolt Head Diameter

Equivalent tensile load, P_t = heel-toe force + axial force = 1116.219 + 316.849 = 1433.068 lb

Total shear load, P_s $= \sqrt{SHEAR1^2 + SHEAR2^2} = \sqrt{161.547^2 + 176.392^2} = 239.189$ lb

5.3 Fastener Analysis *Continued*

To find total tension we must include preload per the following equation:

Total Tension, $P_{total} = PLD_{max} + \phi * n * FS * FF * P_t$

Bolt preload:

$$PLD_{max} = \frac{(1+\Gamma)T_{max}}{K * D}$$

where,

$$n = \frac{1}{\text{Loading Plane Factor}} = \frac{1}{2} = 0.5$$

$$\phi = \text{Joint Stiffness} = \frac{K_b}{K_m + K_b} = 0.266$$

FS = Factor of Safety = 2.0 (ultimate), 1.25 (yield)

FF = Fitting Factor = 1.15

T_{max} = Maximum torque applied to the fastener = 75 in-lb (Reference 11)

Γ = Uncertainty factor = 0.25

K = Typical nut factor = 0.1057 (Reference 11)

D = Diameter of fastener = 0.25 inch

K_j = Spring constant of joint material

K_b = Spring constant of bolt

$$PLD_{max} = \frac{(1+0.25)75}{0.1057 * 0.25} = 3547.777 \text{ lb}$$

$$P_{total} = 3547.777 + 0.266 * 0.5 * 2.0 * 1.15 * 1433.068 = 3986.153 \text{ lb (ultimate)}$$

$$P_{total} = 3547.777 + 0.266 * 0.5 * 1.25 * 1.15 * 1433.068 = 3821.762 \text{ lb (yield)}$$

5.3 Fastener Analysis *Continued*

Fastener allowable loads:

Tensile area, A_t = 0.0364 in^2
Ultimate tensile loads, P_{tu} = $A_t * F_{tu} = 0.0364 * 160000 = 5824$ lb.
Yield tensile load, P_{ty} = $A_t * F_{ty} = 0.0364 * 120000 = 4368$ lb.

Shear area, A_s = 0.0389 in^2
Ultimate shear load, P_{su} = $A_s * F_{su} = 0.0389 * 104000 = 4046$ lb.
Yield shear load, P_{sy} = $A_s * F_{su} = 0.0389 * 78000 = 3034$ lb.

The margin of safety is now calculated using ALLMARG software, which is based on the following interaction equation:

$$\frac{X^3}{A^3} + \frac{Y^2}{B^2} = 1$$

Where,

X = Shear load

A = Allowable shear load

Y = Tensile load

B = Allowable tensile load

Total shear and total tension are input to obtain:

MS_{min} = 0.46 ultimate with preload
MS_{min} = 0.14 yield with preload

5.3 Fastener Analysis *Continued*

Bearing Check:

Bearing on the panel is from the shear load on the fastener. In Figure 5-14a the pull P_s causes the bolt to press against bushing wall, which in turn press against the plate wall. If the pressure is high enough the plate material adjacent to the hole will start to crush and flow thus allowing the bolt and bushing to move which results in the elongated hole as illustrated in Figure 5-14b.

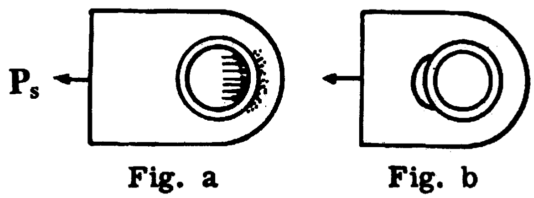


Figure 5-13 Failure by Bearing on Plate

The panels are made of 7075-T7351 Aluminum alloy.

$F_{su} = 38*10^3$ psi

$F_{sy} = F_{su} * F_{tu}/F_{ty} = 38000 * 57000/68000 = 31853$ psi

The bearing strength depends on the ratio of the edge distance over the hole diameter.

for e/D = 2.0
$F_{bru} = 131*10^3$ psi
$F_{bry} = 95*10^3$ psi
for e/D =1.5
$F_{bru} = 102*10^3$ psi
$F_{bry} = 79*10^3$ psi

Since e/D (0.624/0.375 = 1.664) for the floating plate to bottom panel attachment is 1.664, the average bearing strength will be used in the margin of safety calculations based on Lockheed Martin Internal Stress Memo, 61m dated July 1996.

5.3 Fastener Analysis *Continued*

$$F_{br2.0} = \frac{F_{bry} + F_{bru}}{2} = \frac{95*10^3 + 131*10^3}{2} = 113000 \text{ psi}$$

$$F_{br1.5} = \frac{F_{bry} + F_{bru}}{2} = \frac{79*10^3 + 102*10^3}{2} = 90500 \text{ psi}$$

$$f_{br2.0} = \frac{F_{bry}}{F_{bru}} = \frac{95*10^3}{131*10^3} = 0.725$$

$$f_{br1.5} = \frac{F_{bry}}{F_{bru}} = \frac{79*10^3}{102*10^3} = 0.775$$

$$F_{bru}' = \frac{F_{br2.0} - F_{br1.5}}{0.5}\left(e/D - 1.5\right) + F_{br1.5} = 97880.00 \text{ psi}$$

$$F_{bry}' = \frac{F_{br2.0} * f_{br2.0} - F_{br1.5} * f_{br1.5}}{0.5}\left(e/D - 1.5\right) + F_{br1.5} * f_{br1.5} = 74003.80 \text{ psi}$$

Bearing Area and Allowable Bearing Loads:

A_{br} = d * t = 0.375 * 0.3 = 0.1125 in^2
P_{bru} = A_{br} * F_{bru}' = 0.1125 * 97880.00 = 11011.50 lb
P_{bry} = A_{br} * F_{bry}' = 0.1125 * 74003.80 = 8325.428 lb

Margins of safety:

$$MS_u = \frac{P_{bru}}{FS * FF * P_s} - 1 = \frac{11011.50}{2.0 * 1.15 * 239.189} - 1 = 19.016$$

$$MS_y = \frac{P_{bry}}{FS * FF * P_s} - 1 = \frac{8325.428}{1.25 * 1.15 * 239.189} - 1 = 23.213$$

5.3 Fastener Analysis *Continued*

Shear Tear-Out Check

As shown in Figure 5-15a the load Ps causes the bolt to press on the plate around the bolt hole edge. Stresses are produced which tend to cause the portion (a) in Figure 5-15b to tear out as shown. Shear tear out is a function of panel thickness and edge distance.

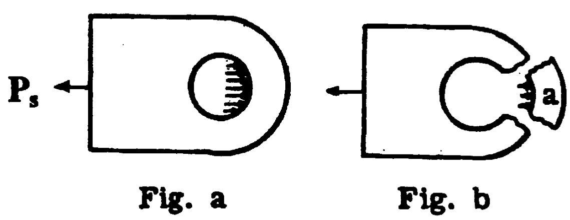


Figure 5-14 Failure by Shear Tear-Out

e = 0.624 in
t = 0.3 in

The shear area is calculated by the following:

$$A_s = 2 * e * t = 2 * 0.624 * 0.3 = 0.3744 \text{ in}^2$$

So, the allowable shear on the panel is

$$P_{su} = A_s * F_{su} = 0.3744 * 38000 = 14227.20 \text{ lb}$$

$$P_{sy} = A_s * F_{sy} = 0.3744 * 31853 = 11925.76 \text{ lb}$$

Margins of safety:

$$MS_u = \frac{P_{su}}{FS * FF * P_s} - 1 = \frac{14227.20}{2.0 * 1.15 * 239.189} - 1 = 24.861$$

$$MS_y = \frac{P_{sy}}{FS * FF * P_s} - 1 = \frac{11925.76}{1.25 * 1.15 * 239.189} - 1 = 33.685$$

5.4 Front Panel Mounting Bolt Analysis

The RC drawer will be mounted to the HRF Rack by six heat-resistant steel ¼ inch fasteners (P/N NAS1351N4) located at the front panel of the drawer. Interface connection for the front panel mounting fasteners are checked for both yield and ultimate strength. These interface fasteners are modeled as rigid elements. Grid point forces for the connecting grid points are recovered from NASTRAN output for the bolt analysis.

The fastener that experiences the highest shear tension stresses is located at the lower-right corner: node ID# 20060 for load case 101. The MOS is obtained by computing preload and adding axial force to it. Sample calculations for this fastener are shown below.

LOAD ID	T1	T2	T3	R1	R2	R3
101	647.017	278.081	128.492	0.00	0.00	0.00

Absolute values of these numbers will be used for conservatism.

Tensile load, P_t = 278.081 lb

Total shear load, P_s $= \sqrt{SHEAR1^2 + SHEAR2^2} = \sqrt{647.017^2 + 128.492^2} = 659.652$ lb

To find total tension we must include preload per the following equation:

$$\text{Total Tension, } P_{total} = PLD_{max} + \phi * n * FS * FF * P_t$$

$$Pu_{total} = 3547.777 + 0.266 * 0.5 * 2.0 * 1.15 * 278.081 = 3632.842 \text{ lb}$$

$$Py_{total} = 3547.777 + 0.266 * 0.5 * 1.25 * 1.15 * 278.081 = 3600.943 \text{ lb}$$

The margin of safety is now calculated using XLBOLT software, which is based on the following interaction equation:

$$\frac{X^3}{A^3} + \frac{Y^2}{B^2} = 1$$

Total shear and total tension are input to obtain the margin of safety:

MS_{min} = 0.465 ultimate with preload

MS_{min} = 0.182 yield with preload

5.4 Front Panel Mounting Bolt Analysis *Continued*

<u>Bearing Check:</u>

The front panel is made of 7075-T7351 Aluminum. Since e/D (0.798/0.272 = 2.934) for the front panel to rack post attachment is 2.934, the average bearing strength for e/D = 2.0 will be used in the margin of safety calculations based on Lockheed Martin Internal Stress Memo, 61m dated July 1996.

$$F_{bru}' = F_{br2.0} = \frac{F_{bry} + F_{bru}}{2} = \frac{95*10^3 + 131*10^3}{2} = 113000.00 \text{ psi}$$

$$f_{br2.0} = \frac{F_{bry}}{F_{bru}} = \frac{95*10^3}{131*10^3} = 0.725$$

$$F_{bry}' = F_{br2.0} * f_{br2.0} = 113000 * 0.725 = 81946.565 \text{ psi}$$

Bearing Area and Allowable Bearing Loads:

A_{br} = d * t = 0.272 * 0.125 = 0.034 in^2
P_{bru} = A_{br} * F_{bru}' = 0.034 * 113000.00 = 3842.00 lb
P_{bry} = A_{br} * F_{bry}' = 0.034 * 81946.565 = 2786.18 lb

Margins of safety:

$$MS_u = \frac{P_{bru}}{FS * FF * P_s} - 1 = \frac{3842.00}{2.0 * 1.15 * 659.652} - 1 = 1.532$$

$$MS_y = \frac{P_{bry}}{FS * FF * P_s} - 1 = \frac{2786.18}{1.25 * 1.15 * 659.652} - 1 = 1.938$$

5.4 Front Panel Mounting Bolt Analysis *Continued*

Shear Tear-Out Check

e = 0.798 in
t = 0.125 in

The shear area is calculated by the following:

$$A_s = 2 * e * t = 2 * 0.798 * 0.125 = 0.1995 \text{ in}^2$$

So, the allowable shear on the panel is

P_{su} = A_s * F_{su} = 0.1995 * 38000 = 7581.00 lb

P_{sy} = A_s * F_{sy} = 0.1995 * 31583 = 6354.67 lb

Margins of safety:

$$MS_u = \frac{P_{su}}{FS * FF * P_s} - 1 = \frac{7581.00}{2.0 * 1.15 * 659.652} - 1 = 3.955$$

$$MS_y = \frac{P_{sy}}{FS * FF * P_s} - 1 = \frac{6354.67}{1.25 * 1.15 * 659.652} - 1 = 5.701$$

Bolt Description	Mounting Bolt
Ult. Shear Load	3034.0
Ult. Tension Load	4368.0
F.S. (Shear)	1.4
F.S. (Tension)	1.0
All. Shear Load	2110.6
All. Tension Load	4368.0
1st Comp of Shear	647.0
2nd Comp of Shear	128.5
Applied Shear	659.7
Applied Tension	3600.9
Margin of Safety (Shear)	0.182
Margin of Safety (Tension)	0.182
Min. Margin of Safety	0.182

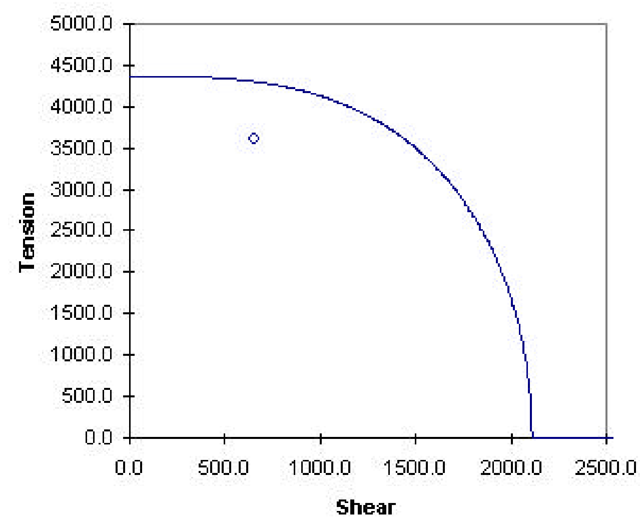


Figure 5-15 Front Panel Mounting Bolt Minimum Margin (Yield)

Bolt Description	Mounting Bolt
Ult. Shear Load	4046.0
Ult. Tension Load	5824.0
F.S. (Shear)	2.3
F.S. (Tension)	1.0
All. Shear Load	1759.1
All. Tension Load	5824.0
1st Comp of Shear	647.0
2nd Comp of Shear	128.5
Applied Shear	659.7
Applied Tension	3632.8
Margin of Safety (Shear)	0.465
Margin of Safety (Tension)	0.465
Min. Margin of Safety	0.465

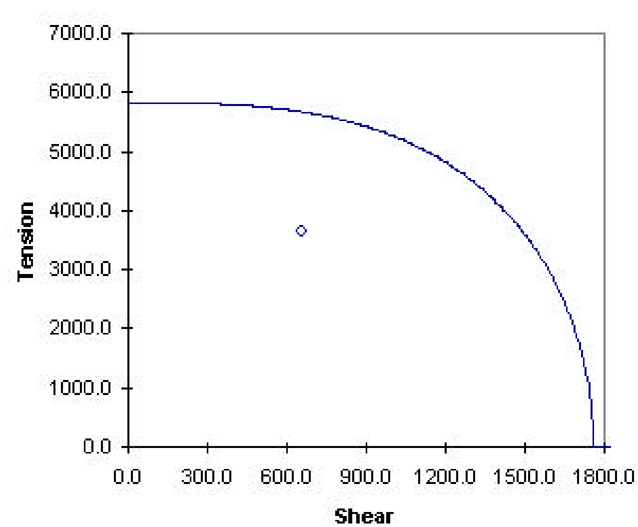


Figure 5-16 Front Panel Mounting Bolt Minimum Margin (Ultimate)

6.0 CREW INDUCED LOADS ANALYSIS

While on orbit, the front panel of the stowage drawer and the front door and the front handles of the RC are exposed to a potential crew-induced load. The crew-induced loads are defined in Section 4.2.

Applied to Stowage Drawer Front Panel:

The front panel, P/N SDG46117717-301, is determined to be one of the weakest and most vulnerable parts for kick load. The front panel is 15.91 inch x 7.082 inch in size, 0.0625 inch thick and is made of Aluminum alloy 7075-T7351. A 125 lb kick load is applied at the center of the panel over a 4 inch x 4 inch square area. The front panel has 0.705 inch deep stiffeners to stiffen the panel. The front panel will act as different rectangular plates, all edges simply supported due to the effect of stiffeners. Therefore a rectangular section 5.407 inch x 3.137 inch is considered for crew induced loads analysis.

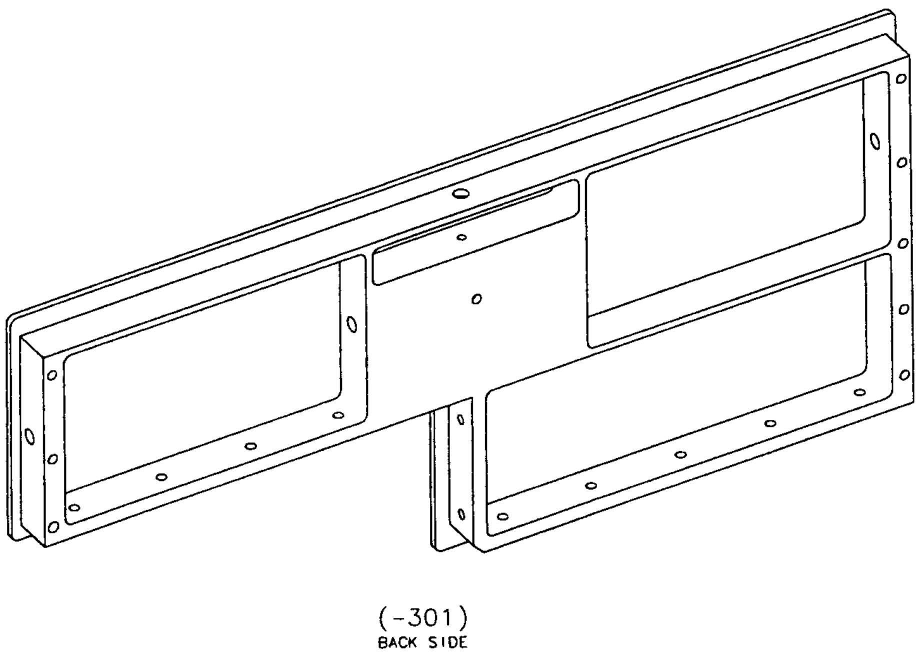


Figure 6-1 RC Stowage Drawer Front Panel

6.0 **CREW INDUCED LOADS ANALYSIS** ***Continued***

Load for 4 x 4 area	= 125 lb
Load for unit area	= 125/16 = 7.8125 lb
Load for 5.407 x 3.137 area	= 7.8125 x 5.407 x 3.137
	= 132.514 lb

Using the formula (Reference 13, Table 26, case 1c) for a uniform load over a central rectangular area of a simply supported flat plate, the maximum bending stress is computed.

Maximum Bending Stress:

$$\sigma = \frac{\beta w}{t^2}$$

where,

w	= crew applied load = 132.514 lb
t	= panel thickness = 0.0625 in
β	= 0.39375 (interpolated value)

$$\sigma = \frac{0.543 * 132.514}{0.0625^2} = 18420.506 \text{ psi}$$

Material properties for 7075-T7351 Aluminum are used to compute Margin of Safety (MS):

$$MS_y = \frac{F_{ty}}{1.25 * \sigma} - 1$$

$$= \frac{57000}{1.25 * 18420.506} - 1 = 1.476$$

$$MS_u = \frac{F_{tu}}{2.0 * \sigma} - 1$$

$$= \frac{68000}{2.0 * 18420.506} - 1 = 0.846$$

6.0 CREW INDUCED LOADS ANALYSIS *Continued*

Applied to the Front Door:

The front door, P/N SEG46117371-301, is determined to be one of the other weakest and most vulnerable parts for kick load. The front panel is 10.60 inch x 10.34 inch in size, 0.0625 inch thick and is made of Aluminum alloy 7075-T7351. There is a 6.0 inch diameter cut-out at the middle of the door and is covered with 0.75 inch thick Lexan. The thickness of Lexan outside the cut-out is 0.312 inch. Conservatively this minimum thickness is used for the analysis. A 125 lb kick load is applied at the center of the door over a 4 inch x 4 inch square area.

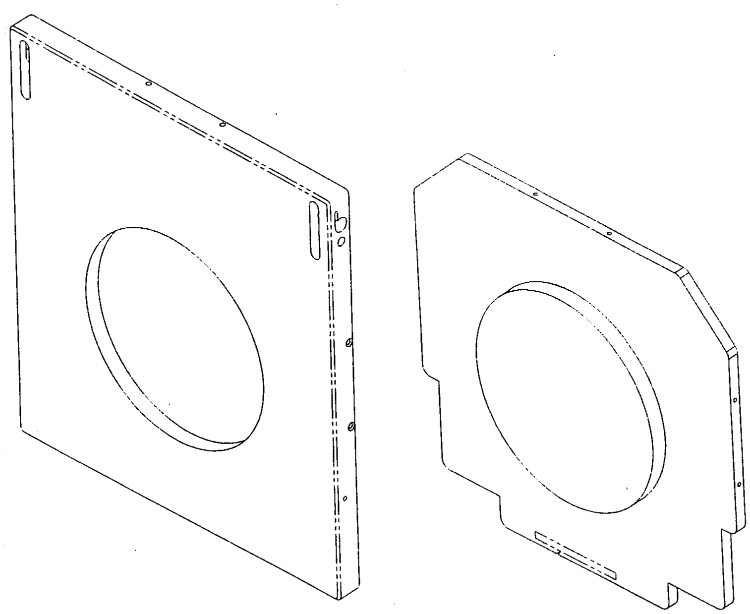


Figure 6-2 RC Front Panel Door

Using the formula (Reference 13, Table 26, case 1c) for a uniform load over a central rectangular area of a simply supported flat plate, the maximum bending stress is computed.

Maximum Bending Stress:

$$\sigma = \frac{\beta w}{t^2}$$

6.0 CREW INDUCED LOADS ANALYSIS *Continued*

where,

w = crew applied load = 125 lb
t = panel thickness = 0.312 in
β = 0.869 (interpolated value)

$$\sigma = \frac{0.869 * 125}{0.312^2} = 1115.888 \text{ psi}$$

Material properties for Lexan are used to compute Margin of Safety (MS):

$$MS_u = \frac{F_{tu}}{2.0 * \sigma} - 1$$
$$= \frac{9600}{2.0 * 1115.888} - 1 = 3.302$$

Applied to the Front Handles:

Front handles are made of 6061-T6 Aluminum alloy. Considered a kick load of 50 lbs at the middle of the handle. Bending stress can be calculate as follows:

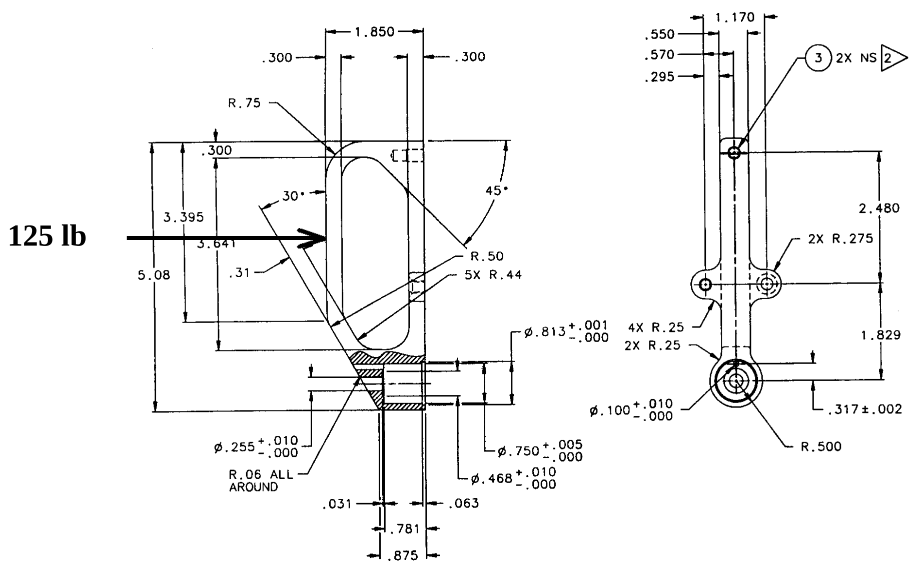


Figure 6-3 RC Front Panel Handle

6.0 CREW INDUCED LOADS ANALYSIS *Continued*

$$\sigma = \text{Bending stress} = \frac{M * C}{I}$$

M = Moment = 50 * 3.941/2 = 98.525 in-lb

C = 0.3/2 = 0.15 inch

$$I = \frac{b * h^3}{12} = \frac{0.55 * 0.3^3}{12} = 1.2375 * 10^{-3}\ \text{in}^4$$

$$\sigma = \frac{98.525 * 0.15}{1.2375^{-3}} = 11942.424\ \text{psi}$$

Material properties for 6061-T6 Aluminum are used to compute Margin of Safety (MS):

$$MS_y = \frac{F_{ty}}{1.25 * \sigma} - 1$$
$$= \frac{35000}{1.25 * 11942.424} - 1 = 1.345$$

$$MS_u = \frac{F_{tu}}{2.0 * \sigma} - 1$$
$$= \frac{42000}{2.0 * 11942.424} - 1 = 0.758$$

7.0 FAIL-SAFE ANALYSIS

Fail-safe analysis demonstrates that redundant load paths exist in the locker. By removing a fastener in a group or a latch, the remaining fasteners or latch are checked to see if they can handle the additional load without failing. There are several failure modes considered for the RC. The following are the fastener failures considered: (1) front panel to rack, (2) slide to side panel, (3) floating plate to bottom panel, (4) motor mounting ring to support assembly, (5) power controller module to bottom panel, (6) compressor to floating plate, and (7) condenser to floating plate.

7.1 Fail-Safe Analysis for Front Panel to Rack Fastener

The front panel of the RC is mounted to the rack by six one-quarter-inch heat-resistant steel fasteners (NAS1351N4). The lowest MOS for the front panel attachment occurs at the fastener represented by node ID #20060. For fail-safe analysis, assume this bolt fails and redistribute all the loads on the adjacent bolts. The NASTRAN static model is re-run in this configuration and new forces are produced. All the panels, beams, and rivets show positive margin of safety. The following is a sample calculation for the highly loaded fastener represented by node ID #20127 for load case 104.

LOAD ID	T1	T2	T3	R1	R2	R3
104	658.774	-509.444	-132.864	0.00	0.00	0.00

Absolute values of these numbers will be used for conservatism.

Tensile load, P_t = 509.444 lb.

Total shear load, P_s = $\sqrt{SHEAR1^2 + SHEAR2^2} = \sqrt{658.774^2 + 132.864^2}$ = 672.039 lb.

To find total tension we must include preload per the following equation:

$$\text{Total Tension, } P_{total} = PLD_{max} + \phi * n * FS * FF * P_t$$

$$PLD_{max} = 3547.777 \text{ lb}$$

$$Pu_{total} = 3547.777 + 0.266 * 0.5 * 1.0 * 1.15 * 509.444 = 3625.697 \text{ lb}$$

The margin of safety is now calculated using XLBOLT software which is based on the total shear and total tension are input to obtain the margin of safety:

MS_{min} = 0.584 ultimate with preload

7.1 Fail-Safe Analysis for Front Panel to Rack Fastener *Concluded*

Table 7.1 Front Panel Minimum Margins (Fail-Safe)

ELEMENT ID	LOAD ID	FIBER DISTANCE	STRESSES IN ELEMENT COORDINATE SYSTEM			PRINCIPAL STRESSES (ZERO SHEAR)			MARGIN OF SAFETY
			NORMAL-X	NORMAL-Y	SHEAR-XY	MAJOR	MINOR	VON MISES	ULTIMATE
20494	104	6.50E-02	-7.31E+03	-3.02E+04	-2.90E+03	-6945.50	-30583.07	27769.58	1.223
20676	101	-6.50E-02	8.11E+03	2.61E+04	6.12E+02	26079.46	8093.91	23120.66	1.607
20496	104	6.50E-02	-8.30E+03	-2.44E+04	-1.82E+03	-8099.37	-24649.51	21761.27	1.759
20542	103	6.50E-02	-8.96E+03	-2.46E+04	1.29E+03	-8852.87	-24697.69	21672.65	1.753
20397	104	-6.25E-02	6.89E+03	2.35E+04	3.22E+03	24080.26	6285.93	21633.42	1.824
20013	101	6.25E-02	-2.30E+04	-7.61E+03	2.55E+03	-7203.05	-23449.23	20804.91	1.900
20674	101	-6.50E-02	7.19E+03	2.33E+04	-6.21E+02	23373.27	7169.99	20739.63	1.909
20540	103	6.50E-02	-8.55E+03	-2.16E+04	-2.91E+03	-7934.89	-22174.51	19460.70	2.067
20399	104	6.25E-02	-5.37E+03	-2.05E+04	-2.63E+03	-4929.42	-20965.05	18986.49	2.243
20018	101	6.25E-02	-2.12E+04	-8.33E+03	-2.06E+03	-8006.46	-21559.19	18875.63	2.154
20634	102	-6.50E-02	6.96E+03	2.04E+04	-7.74E+02	20447.05	6918.15	18013.52	2.326
20111	104	-6.25E-02	8.46E+03	2.04E+04	6.15E+02	20476.81	8429.17	17825.49	2.321
20636	102	-6.50E-02	7.75E+03	1.88E+04	3.12E+03	19653.92	6929.53	17265.65	2.460
20518	104	6.50E-02	-6.30E+03	-1.86E+04	-7.88E+02	-6246.24	-18668.93	16460.06	2.642
20396	104	-6.25E-02	1.50E+03	1.71E+04	-5.12E+02	17139.58	1485.07	16447.40	2.967
20398	103	6.25E-02	-2.93E+03	-1.58E+04	-4.23E+03	-1666.88	-17111.16	16341.61	2.974
20520	103	6.50E-02	-6.18E+03	-1.68E+04	1.42E+03	-5988.83	-16989.18	14924.91	3.003
20652	102	-6.50E-02	5.46E+03	1.68E+04	-2.30E+00	16808.60	5461.85	14851.08	3.046
20199	104	-6.25E-02	5.62E+03	1.57E+04	2.17E+03	16178.99	5171.67	14312.00	3.203
20401	104	6.25E-02	-1.11E+04	-4.37E+03	-5.56E+03	-1243.84	-14254.68	13675.25	3.770
20073	102	6.25E-02	-1.46E+04	-5.68E+03	-1.56E+03	-5415.12	-14905.17	13068.07	3.562
20120	104	6.25E-02	-9.77E+03	-1.17E+04	4.10E+03	-6510.86	-14935.15	12969.56	3.553
20331	103	-6.25E-02	-1.46E+04	-5.60E+03	9.16E+02	-5507.05	-14655.75	12822.19	3.640
20654	101	-6.50E-02	4.45E+03	1.41E+04	1.26E+03	14249.42	4286.18	12662.61	3.772
20207	103	-6.25E-02	4.47E+03	1.38E+04	-1.67E+03	14111.96	4176.91	12555.86	3.819

Bolt Description	Mounting Bolt
Ult. Shear Load	4046.0
Ult. Tension Load	5824.0
F.S. (Shear)	1.2
F.S. (Tension)	1.0
All. Shear Load	3518.3
All. Tension Load	5824.0
1st Comp of Shear	658.8
2nd Comp of Shear	-132.9
Applied Shear	672.0
Applied Tension	3625.7
Margin of Safety (Shear)	0.584
Margin of Safety (Tension)	0.584
Min. Margin of Safety	0.584

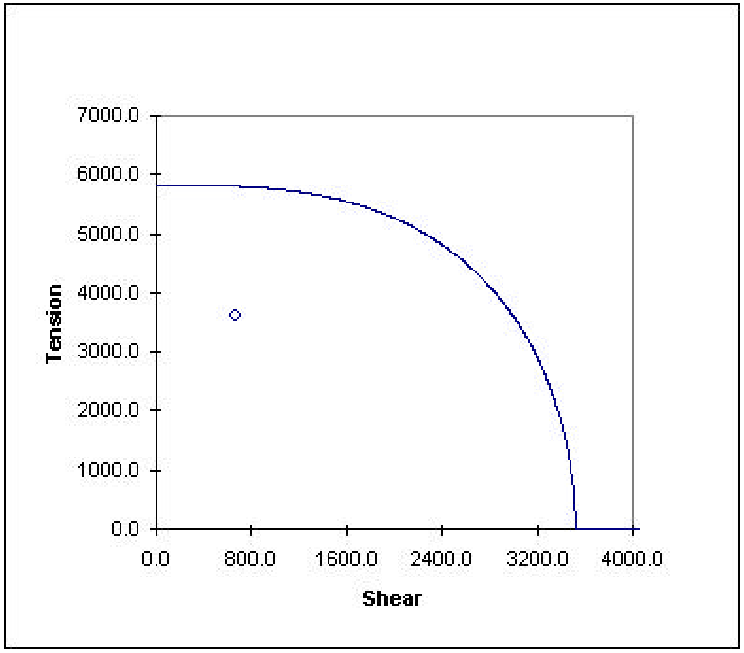


Figure 7-1 Rear Panel Mounting Bolt, Fail-Safe Minimum Margin (Ultimate)

7.2 Fail-Safe Analysis for Slide to Side Panel Fastener

Each slide of the RC is connected to the side panel by 12 #10 corrosion resistant steel fasteners (NAS1101-3). The highly loaded fastener (Element ID #47236) is in the left side panel. For fail-safe analysis, assume this fastener fails and redistribute all the loads on the adjacent fasteners. The NASTRAN static model is re-run in this configuration and new forces are produced. All the panels, beams, and fasteners show positive margins of safety. Tables 7.2 and 7.3 show the margin of safety for the slides and the slide to the side panel fasteners.

Table 7.2 Slides Minimum Margins (Fail-Safe)

Left Slides - PBAR 501250

ELEMENT ID	LOAD CASE	TENSILE STRESS	SHEAR STRESS	PRINCIPAL STRESS	VONMISES STRESS	MINIMUM M.S. ULTIMATE
42546	103	7127.03	6643.13	11102.07	13534.70	5.12
42569	101	7855.29	5610.05	10775.94	12494.94	5.31
42522	102	8756.03	2153.26	9256.90	9517.23	6.35
42547	104	6815.07	3946.06	8621.23	9651.91	6.89
42571	103	5766.96	4247.46	8017.23	9347.76	7.48
42572	104	5978.07	3174.22	7349.08	8121.84	8.25
42521	103	6474.33	2455.97	7300.54	7746.76	8.31
42545	103	3521.90	4250.25	6361.55	8160.73	9.69
42570	102	5438.37	2156.05	6189.42	6597.08	9.99
42501	103	4293.55	3371.71	6143.91	7248.44	10.07
42568	101	3795.24	3052.03	5491.49	6507.58	11.38
42548	104	5045.29	761.15	5157.62	5214.69	12.18
42502	102	4214.88	1654.22	4786.57	5096.52	13.21
42520	102	4228.55	1608.37	4770.78	5063.72	13.25
42549	104	3805.41	763.81	3953.00	4028.82	16.20
42523	103	1983.58	2644.17	3815.84	4990.94	16.82
42524	102	3293.80	1148.69	3654.82	3848.06	17.61
42525	102	3251.05	1183.53	3636.26	3843.38	17.70
42503	102	2662.69	1656.89	3456.85	3914.82	18.67
42509	101	2602.67	1413.31	3222.51	3572.98	20.10
42555	102	2342.76	1624.82	3174.42	3661.78	20.42
42566	107	2257.51	1592.42	3080.65	3564.23	21.07
42510	106	2996.79	294.63	3025.49	3039.93	21.48
42544	106	1266.62	2140.98	2866.00	3918.64	22.73
42550	105	2753.51	468.93	2831.18	2870.81	23.02
42543	106	1029.77	2141.15	2717.07	3848.89	24.03
42518	103	638.61	2226.93	2569.01	3909.67	25.47
42554	102	2343.92	678.95	2526.39	2622.39	25.92
42511	106	2466.75	297.31	2502.08	2519.93	26.18
42526	102	1899.42	1186.20	2469.25	2798.03	26.54

42565	108	2318.53	263.32	2348.06	2362.96	27.96
42541	106	1435.15	1454.98	2339.89	2900.10	28.06

7.2 Fail-Safe Analysis for Slide to Side Panel Fastener *Concluded*

Table 7.3 Slide to Side Panel Fastener Minimum Margins (Fail-Safe)

Left Slide to Left Side Panel - PBAR 501251

FASTENER ID	LOAD CASE	TENSION +PRELOAD ULTIMATE	TENS+BEND +PRELOAD ULTIMATE	SHEAR LOAD	MINIMUM M.S. W/PLD ULTIMATE	MINIMUM BEARING ULTIMATE	MINIMUM SHEAR TEAR-OUT
47235	103	1670.37	1779.89	193.10	0.80	8.84	18.38
47234	101	1678.34	1778.71	152.29	0.80	11.25	23.12
47223	104	1645.68	1726.39	193.49	0.85	8.82	18.34
47211	103	1641.88	1707.59	125.68	0.87	14.11	28.75
47201	103	1633.79	1704.36	186.85	0.87	9.03	18.75
47212	102	1635.87	1677.85	129.14	0.91	13.72	27.98
47233	108	1636.34	1672.52	108.91	0.91	12.39	25.37
47222	106	1634.54	1667.52	82.71	0.92	15.82	32.13
47205	101	1640.83	1660.59	31.75	0.93	37.77	75.37
47210	106	1632.64	1658.23	37.18	0.93	26.05	52.27
47232	101	1631.70	1658.09	59.07	0.93	31.17	62.36
47221	103	1626.81	1657.64	59.87	0.93	30.74	61.52
47227	102	1628.65	1649.42	43.55	0.94	42.64	84.96
47209	104	1627.75	1647.75	60.37	0.94	30.48	61.00
47204	101	1628.80	1647.68	63.74	0.94	28.82	57.73
47208	106	1628.00	1645.82	53.49	0.94	30.15	60.35
47216	102	1629.86	1645.20	35.07	0.95	53.19	105.73
47224	107	1626.87	1644.58	27.71	0.95	46.78	93.11
47206	107	1626.33	1644.13	60.41	0.95	28.38	56.87
47231	104	1629.36	1644.00	25.69	0.95	66.09	131.12
47217	101	1624.41	1642.73	61.22	0.95	30.04	60.14
47207	122	1626.05	1642.73	51.84	0.95	35.56	71.00
47202	107	1629.55	1642.65	31.78	0.95	29.97	60.00
47228	101	1625.31	1642.50	56.12	0.95	32.86	65.70
47203	106	1626.61	1640.39	35.10	0.95	46.49	92.54
47225	107	1625.96	1640.29	38.30	0.95	38.97	77.71
47218	101	1625.00	1640.06	47.21	0.95	39.25	78.28
47220	103	1625.44	1639.23	25.45	0.95	73.67	146.06
47215	102	1628.28	1639.11	30.84	0.95	60.63	120.38
47229	102	1624.37	1639.06	45.67	0.95	40.61	80.95
47230	107	1630.07	1639.10	26.74	0.95	59.45	118.05

MAXIMUM CONNECTOR TENSION IS 175.17
MAXIMUM CONNECTOR SHEAR IS 193.49

7.3 Fail-Safe Analysis for Floating Plate to Bottom Panel Fastener

The floating plate is connected to the bottom panel by four one-quarter-inch heat-resistant steel fasteners (NAS1351N4). The highly loaded fastener is represented by element ID #47602. For fail-safe analysis, assume this fastener fails and redistribute all the loads on the adjacent fasteners. The NASTRAN static model is re-run in this configuration and new forces are produced. All the panels, beams, and fasteners show positive margins of safety. Tables 7-4 and 7-5 show the margin of safety for the floating plate and the floating plate to the bottom panel fasteners.

Table 7.4 Floating Plate Minimum Margins (Fail-Safe)

ELEMENT ID	LOAD ID	FIBER DISTANCE	STRESSES IN ELEMENT COORDINATE SYSTEM			PRINCIPAL STRESSES (ZERO SHEAR)			MARGIN OF SAFETY
			NORMAL-X	NORMAL-Y	SHEAR-XY	MAJOR	MINOR	VON MISES	ULTIMATE
35057	102	-6.25E-02	1.32E+04	2.14E+03	9.30E+02	13316.76	2061.69	12414.98	4.106
35052	102	6.25E-02	-1.21E+04	-2.05E+03	-1.18E+03	-1911.66	-12208.91	11374.21	4.570
35062	102	-6.25E-02	-1.15E+04	-1.86E+03	9.37E+02	-1772.98	-11626.77	10849.48	4.849
35022	102	-6.25E-02	9.91E+03	1.30E+03	5.88E+02	9950.57	1262.08	9383.41	5.834
35166	102	9.38E-02	-8.04E+03	-7.83E+01	-2.63E+03	713.67	-8833.64	9211.23	6.698
35174	102	9.38E-02	7.81E+03	2.02E+02	-2.38E+03	8489.12	-480.50	8739.28	7.010
35025	102	6.25E-02	-7.20E+03	-2.37E+01	2.76E+03	916.17	-8140.46	8635.07	7.353
35154	102	-9.38E-02	-7.52E+03	-3.03E+02	2.43E+03	439.23	-8265.23	8493.37	7.227
35033	102	6.25E-02	7.22E+03	2.35E+02	2.51E+03	8025.91	-573.49	8327.48	7.473
35105	102	-6.25E-02	-8.31E+03	-2.06E+03	2.08E+03	-1431.00	-8940.44	8317.78	6.606
35167	102	9.38E-02	-7.88E+03	-1.18E+03	-2.03E+03	-606.23	-8446.07	8159.86	7.051
35058	102	6.25E-02	6.61E+03	5.86E+02	-2.95E+03	7810.08	-617.96	8136.68	7.707
35051	102	-6.25E-02	-6.93E+03	-6.43E+02	2.50E+03	227.74	-7801.91	7918.24	7.716
35043	102	-6.25E-02	-8.36E+03	-1.23E+03	1.60E+02	-1227.02	-8368.50	7827.45	7.126
35175	102	9.38E-02	7.53E+03	1.03E+03	-1.76E+03	7977.33	582.87	7702.45	7.524

Table 7.5 Floating Plate to Bottom Panel Fastener Minimum Margins (Fail-Safe)

Floating Plate to Bottom Panel - PBAR 501271

FASTENER ID	LOAD CASE	TENSION +PRELOAD ULTIMATE	TENS+BEND +PRELOAD ULTIMATE	SHEAR LOAD	MINIMUM M.S. W/PLD ULTIMATE	MINIMUM BEARING ULTIMATE	MINIMUM SHEAR TEAR-OUT
47601	103	3613.99	3838.71	314.84	0.52	16.49	21.59
47603	105	3604.41	3799.95	273.95	0.53	17.13	22.42
47604	101	3614.75	3741.81	178.01	0.56	29.93	38.96

MAXIMUM CONNECTOR TENSION IS 548.60
MAXIMUM CONNECTOR SHEAR IS 314.84

7.4 Fail-Safe Analysis for Motor Mounting Ring to Support Assembly Fastener

The motor mounting ring is connected to the support assembly by three one-quarter-inch heat-resistant steel fasteners (NAS1351N4). The highly loaded fastener is represented by element ID #47702. For fail-safe analysis, assume this fastener fails and redistribute all the loads on the adjacent fasteners. The NASTRAN static model is re-run in this configuration and new forces are produced. All the panels, beams, and fasteners show positive margins of safety. Tables 7-6 and 7-7 show the margin of safety for the motor mounting ring and the motor mounting ring to the support assembly fasteners.

Table 7.6 Motor Mounting Ring Minimum Margins (Fail-Safe)

ELEMENT ID	LOAD ID	FIBER DISTANCE	STRESSES IN ELEMENT COORDINATE SYSTEM			PRINCIPAL STRESSES (ZERO SHEAR)			MARGIN OF SAFETY
			NORMAL-X	NORMAL-Y	SHEAR-XY	MAJOR	MINOR	VON MISES	ULTIMATE
37733	115	6.25E-02	1.61E+04	2.39E+04	-9.18E+03	29983.62	10038.08	26434.87	1.268
37736	110	6.25E-02	1.01E+04	2.20E+04	-5.42E+03	24110.63	8016.16	21267.51	1.820
37844	116	6.25E-02	1.06E+04	1.97E+04	6.65E+03	23222.47	7129.80	20604.51	1.928
37735	116	6.25E-02	7.18E+03	2.20E+04	2.28E+03	22316.86	6833.52	19804.96	2.047
37703	116	6.25E-02	-1.24E+04	-2.00E+04	-5.18E+03	-9781.77	-22631.31	19659.22	2.005
37734	116	6.25E-02	-3.02E+03	-1.53E+04	-7.11E+03	225.73	-18598.15	18712.03	2.656
37846	109	6.25E-02	-1.32E+04	2.17E+03	-6.49E+03	4533.51	-15617.18	18309.82	3.354
37845	110	6.25E-02	3.39E+02	1.52E+04	-4.80E+03	16578.81	-1081.55	17145.19	3.102
37704	115	6.25E-02	7.66E+03	1.90E+04	-2.10E+03	19398.65	7283.73	16972.50	2.505
37740	110	6.25E-02	-6.98E+03	-5.74E+03	4.23E+03	-2090.18	-10631.60	9755.91	5.396
37828	110	-1.88E-01	3.82E+03	1.98E+03	-4.34E+03	7336.61	-1541.25	8216.38	8.269
37743	109	6.25E-02	2.70E+03	6.34E+03	3.30E+03	8291.35	752.80	7941.76	7.201
37795	109	1.88E-01	5.16E+02	5.70E+03	3.24E+03	7258.48	-1045.34	7833.63	8.368
37714	116	6.25E-02	4.65E+03	6.15E+03	-2.73E+03	8236.42	2566.30	7299.82	7.256
37739	115	6.25E-02	2.66E+03	6.36E+03	-2.08E+03	7291.31	1726.87	6599.56	8.326

Table 7.7 Motor Mounting Ring to Support Assy. Fastener Minimum Margins (Fail-Safe)

Motor Ring to Support Assembly - PBAR 501271

FASTENER ID	LOAD CASE	TENSION +PRELOAD ULTIMATE	TENS+BEND +PRELOAD ULTIMATE	SHEAR LOAD	MINIMUM M.S. W/PLD ULTIMATE	MINIMUM BEARING ULTIMATE	MINIMUM SHEAR TEAR-OUT
47701	115	3555.27	3620.84	40.93	0.61	14.25	30.27
47703	116	3554.67	3609.11	17.02	0.61	18.74	39.47

MAXIMUM TENSION FOR ALL CONNECTORS IS 48.98
MAXIMUM SHEAR FOR ALL CONNECTORS IS 94.95

7.5 Fail-Safe Analysis for Power Controller Module to Bottom Panel Fastener

The power controller module is mounted to the bottom panel by four #10 corrosion resistant steel fasteners (NAS1101-3). The lowest MOS for the power controller module attachment occurs at the fastener represented by node ID #23069. For fail-safe analysis, assume this bolt fails and redistribute all the loads on the adjacent bolts. The NASTRAN static model is re-run in this configuration and new forces are produced. The following is a sample calculation for the highly loaded fastener represented by node ID #23506 for load case 104.

LOAD ID	T1	T2	T3	R1	R2	R3
104	-372.983	434.512	402.595	0.00	0.00	0.00

Absolute values of these numbers will be used for conservatism.

Tensile load, P_t = 402.595 lb.

Total shear load, P_s = $\sqrt{SHEAR1^2 + SHEAR2^2} = \sqrt{372.983^2 + 434.512^2}$ = 572.640 lb.

To find total tension we must include preload per the following equation:

$$\text{Total Tension, } P_{total} = PLD_{max} + \phi * n * FS * FF * P_t$$

$$PLD_{max} = 1625.234 \text{ lb}$$

$$Pu_{total} = 1625.234 + 0.266 * 0.5 * 1.0 * 1.15 * 402.595 = 1686.810 \text{ lb}$$

The margin of safety is now calculated using XLBOLT software which is based on the total shear and total tension are input to obtain the margin of safety:

MS_{min} = 0.762 ultimate with preload

Prepared By	Shaji Ommen	LOCKHEED MARTIN SPACE OPERATIONS Mechanical Systems Analysis Department	Date 9 – 25 – 00	File Name
Checked By	D. Van		Drawing No. SED46117400 – 301	
Title	Refrigerated Centrifuge (RC) Stress Analysis Report		Report No. LMSEAT 33513	

Bolt Description	Power Converter
Ult. Shear Load	2246.0
Ult. Tension Load	3200.0
F.S. (Shear)	1.2
F.S. (Tension)	1.0
All. Shear Load	1953.0
All. Tension Load	3200.0
1st Comp of Shear	-373.0
2nd Comp of Shear	434.5
Applied Shear	572.6
Applied Tension	1686.8
Margin of Safety (Shear)	0.762
Margin of Safety (Tension)	0.762
Min. Margin of Safety	0.762

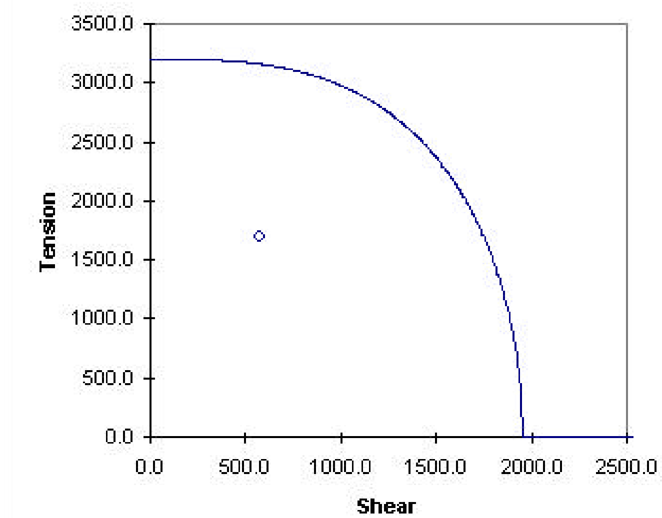


Figure 7-2 Power Converter Module Mounting Bolt, Fail-Safe Minimum Margin (Ultimate)

7.6 Fail-Safe Analysis for Compressor to Floating Plate Fastener

The compressor is mounted to the floating plate by four one-quarter-inch heat resistant steel fasteners (NAS1351N4). The lowest MOS for the compressor attachment occurs at the fastener represented by node ID #35150. For fail-safe analysis, assume this bolt fails and redistribute all the loads on the adjacent bolts. The NASTRAN static model is re-run in this configuration and new forces are produced. The following is a sample calculation for the highly loaded fastener represented by node ID #35145 for load case 101.

LOAD ID	T1	T2	T3	R1	R2	R3
101	-54.329	-469.650	-259.574	0.00	0.00	0.00

Absolute values of these numbers will be used for conservatism.

Tensile load, P_t = 259.574 lb.

Total shear load, P_s = $\sqrt{SHEAR1^2 + SHEAR2^2} = \sqrt{54.329^2 + 469.65^2}$ = 472.782 lb.

To find total tension we must include preload per the following equation:

Total Tension, $P_{total} = PLD_{max} + \phi * n * FS * FF * P_t$

$$PLD_{max} = 3547.777 \text{ lb}$$

$$Pu_{total} = 3547.777 + 0.266 * 0.5 * 1.0 * 1.15 * 259.574 = 3587.479 \text{ lb}$$

The margin of safety is now calculated using XLBOLT software which is based on the total shear and total tension are input to obtain the margin of safety:

MS_{min} = 0.615 ultimate with preload

Bolt Description	Compressor
Ult. Shear Load	4046.0
Ult. Tension Load	5824.0
F.S. (Shear)	1.2
F.S. (Tension)	1.0
All. Shear Load	3518.3
All. Tension Load	5824.0
1st Comp of Shear	-54.3
2nd Comp of Shear	-469.7
Applied Shear	472.8
Applied Tension	3587.5
Margin of Safety (Shear)	0.615
Margin of Safety (Tension)	0.615
Min. Margin of Safety	0.615

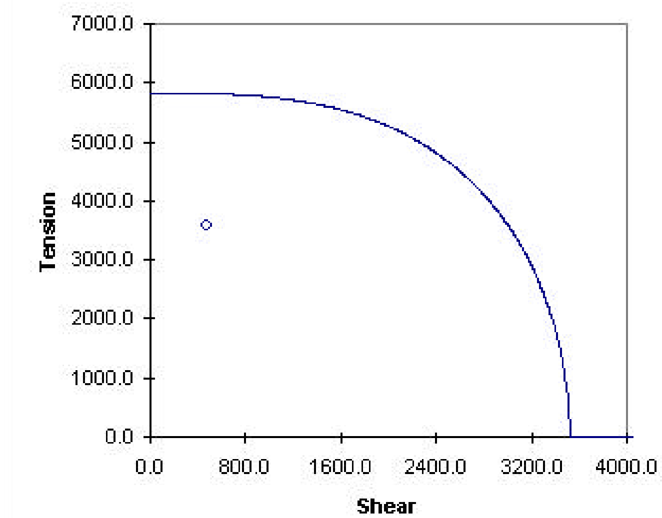


Figure 7-3 Compressor Mounting Bolt, Fail-Safe Minimum Margin (Ultimate)

7.7 Fail-Safe Analysis for Condenser to Floating Plate Fastener

The condenser is mounted to the floating plate by four #10 corrosion resistant steel fasteners (NAS1101-3). The lowest MOS for the condenser attachment occurs at the fastener represented by node ID #35060. For fail-safe analysis, assume this bolt fails and redistribute all the loads on the adjacent bolts. The NASTRAN static model is re-run in this configuration and new forces are produced. The following is a sample calculation for the highly loaded fastener represented by node ID #35014 for load case 103.

LOAD ID	T1	T2	T3	R1	R2	R3
103	8.809	-90.697	93.322	0.00	0.00	0.00

Absolute values of these numbers will be used for conservatism.

Tensile load, P_t = 93.322 lb.

Total shear load, P_s = $\sqrt{SHEAR1^2 + SHEAR2^2} = \sqrt{8.809^2 + 90.697^2}$ = 91.124 lb.

To find total tension we must include preload per the following equation:

Total Tension, $P_{total} = PLD_{max} + \phi * n * FS * FF * P_t$

$$PLD_{max} = 1625.234 \text{ lb}$$

$$Pu_{total} = 1625.234 + 0.266 * 0.5 * 1.0 * 1.15 * 93.322 = 1639.508 \text{ lb}$$

The margin of safety is now calculated using XLBOLT software which is based on the total shear and total tension are input to obtain the margin of safety:

MS_{min} = 0.954 ultimate with preload

Bolt Description	Condenser
Ult. Shear Load	2246.0
Ult. Tension Load	3200.0
F.S. (Shear)	1.2
F.S. (Tension)	1.0
All. Shear Load	1953.0
All. Tension Load	3200.0
1st Comp of Shear	8.8
2nd Comp of Shear	-90.7
Applied Shear	91.1
Applied Tension	1639.5
Margin of Safety (Shear)	0.951
Margin of Safety (Tension)	0.951
Min. Margin of Safety	0.951

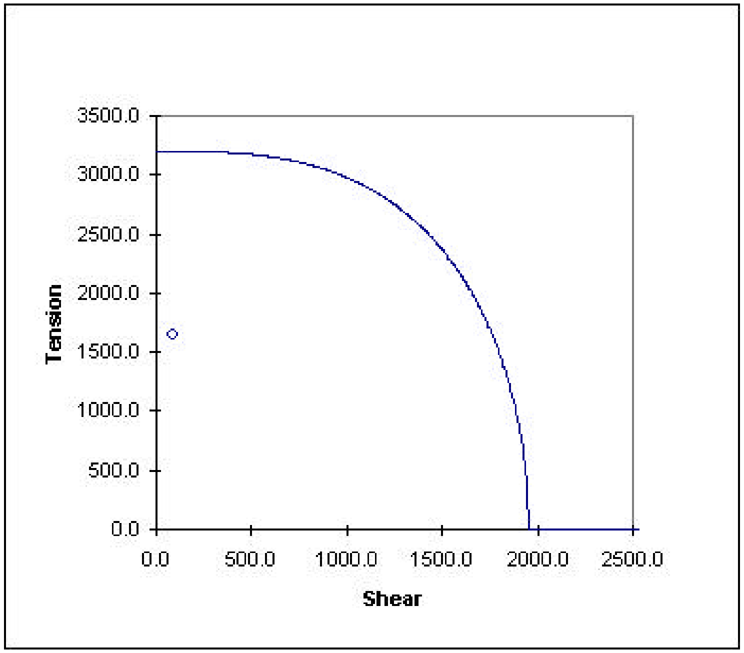


Figure 7-4 Condenser Mounting Bolt, Fail-Safe Minimum Margin (Ultimate)

8.0 SAFE RETURN CONFIGURATION ANALYSIS

According to the interpretation letter TA-93-037, "Structural Integrity Following Mechanism Failure", mechanism failure(s), which result in limit load redistribution will require structural verification on the redistributed loads if the failed condition is credible. When two-failure tolerance cannot be implemented, structural verification of the redistributed load path is required and the 1.4 factor of safety on limit loads must be maintained.

For the Refrigerated Centrifuge, the two credible failures are (1) floating plate to bottom panel fastener failure and (2) motor mounting ring to support assembly fastener failure. During on orbit operation the fasteners that connect the floating plate to the bottom panel and the ones that connect the motor mounting ring to support assembly will be removed and connected by vibration isolators. In case of landing these isolators should be replaced by fasteners.

8.1 Floating Plate to Bottom Panel Fastener Failure

The floating plate to bottom panel fastener fail-safe analysis result described in Section 7.3 is used for the safe return configuration analysis. Margins of safety are calculated with a factor of safety 1.4. All the panels, beams, and fasteners show positive margin of safety. Tables 8-1 and 8-2 show the margins of safety for the floating plate and the floating plate to the bottom panel fasteners.

Table 8.1 Floating Plate Minimum Margins (Safe Return)

ELEMENT ID	LOAD ID	FIBER DISTANCE	STRESSES IN ELEMENT COORDINATE SYSTEM			PRINCIPAL STRESSES (ZERO SHEAR)			MARGIN OF SAFETY
			NORMAL-X	NORMAL-Y	SHEAR-XY	MAJOR	MINOR	VON MISES	ULTIMATE
35057	102	-6.25E-02	1.32E+04	2.14E+03	9.30E+02	13316.76	2061.69	12414.98	2.647
35052	102	6.25E-02	-1.21E+04	-2.05E+03	-1.18E+03	-1911.66	-12208.91	11374.21	2.978
35062	102	-6.25E-02	-1.15E+04	-1.86E+03	9.37E+02	-1772.98	-11626.77	10849.48	3.178
35022	102	-6.25E-02	9.91E+03	1.30E+03	5.88E+02	9950.57	1262.08	9383.41	3.881
35166	102	9.38E-02	-8.04E+03	-7.83E+01	-2.63E+03	713.67	-8833.64	9211.23	4.498
35174	102	9.38E-02	7.81E+03	2.02E+02	-2.38E+03	8489.12	-480.50	8739.28	4.722
35025	102	6.25E-02	-7.20E+03	-2.37E+01	2.76E+03	916.17	-8140.46	8635.07	4.967
35154	102	-9.38E-02	-7.52E+03	-3.03E+02	2.43E+03	439.23	-8265.23	8493.37	4.877
35033	102	6.25E-02	7.22E+03	2.35E+02	2.51E+03	8025.91	-573.49	8327.48	5.052
35105	102	-6.25E-02	-8.31E+03	-2.06E+03	2.08E+03	-1431.00	-8940.44	8317.78	4.433
35167	102	9.38E-02	-7.88E+03	-1.18E+03	-2.03E+03	-606.23	-8446.07	8159.86	4.751
35058	102	6.25E-02	6.61E+03	5.86E+02	-2.95E+03	7810.08	-617.96	8136.68	5.219
35051	102	-6.25E-02	-6.93E+03	-6.43E+02	2.50E+03	227.74	-7801.91	7918.24	5.226
35043	102	-6.25E-02	-8.36E+03	-1.23E+03	1.60E+02	-1227.02	-8368.50	7827.45	4.804
35175	102	9.38E-02	7.53E+03	1.03E+03	-1.76E+03	7977.33	582.87	7702.45	5.089

Table 8.2 Floating Plate to Bottom Panel Fastener Minimum Margins (Safe Return)

Floating Plate to Bottom Panel - PBAR 501271

FASTENER ID	LOAD CASE	TENSION +PRELOAD ULTIMATE	TENS+BEND +PRELOAD ULTIMATE	SHEAR LOAD	MINIMUM M.S. W/PLD ULTIMATE	MINIMUM BEARING ULTIMATE	MINIMUM SHEAR TEAR-OUT
47601	103	3640.48	3955.08	314.84	0.47	16.49	21.59
47603	105	3627.06	3900.81	273.95	0.49	17.13	22.42
47604	101	3641.54	3819.42	178.01	0.52	29.93	38.96

MAXIMUM CONNECTOR TENSION IS 548.60
MAXIMUM CONNECTOR SHEAR IS 314.84

8.2 Motor Mounting Ring to Support Assembly Fastener Failure

The motor mounting ring to support assembly fastener fail-safe analysis result described in Section 7.4 is used for the safe return configuration analysis. Margins of safety are calculated with a factor of safety 1.4. All the panels, beams, and fasteners show positive margin of safety. Tables 8-3 and 8-4 show the margins of safety for the mounting ring and the motor mounting ring to the support assembly fasteners.

Table 8.3 Motor Mounting Ring Minimum Margins (Safe Return)

ELEMENT ID	LOAD ID	FIBER DISTANCE	STRESSES IN ELEMENT COORDINATE SYSTEM			PRINCIPAL STRESSES (ZERO SHEAR)			MARGIN OF SAFETY
			NORMAL-X	NORMAL-Y	SHEAR-XY	MAJOR	MINOR	VON MISES	ULTIMATE
37733	115	6.25E-02	1.61E+04	2.39E+04	-9.18E+03	29983.62	10038.08	26434.87	0.620
37736	110	6.25E-02	1.01E+04	2.20E+04	-5.42E+03	24110.63	8016.16	21267.51	1.015
37844	116	6.25E-02	1.06E+04	1.97E+04	6.65E+03	23222.47	7129.80	20604.51	1.092
37735	116	6.25E-02	7.18E+03	2.20E+04	2.28E+03	22316.86	6833.52	19804.96	1.176
37703	116	6.25E-02	-1.24E+04	-2.00E+04	-5.18E+03	-9781.77	-22631.31	19659.22	1.146
37734	116	6.25E-02	-3.02E+03	-1.53E+04	-7.11E+03	225.73	-18598.15	18712.03	1.612
37846	109	6.25E-02	-1.32E+04	2.17E+03	-6.49E+03	4533.51	-15617.18	18309.82	2.110
37845	110	6.25E-02	3.39E+02	1.52E+04	-4.80E+03	16578.81	-1081.55	17145.19	1.930
37704	115	6.25E-02	7.66E+03	1.90E+04	-2.10E+03	19398.65	7283.73	16972.50	1.504
37740	110	6.25E-02	-6.98E+03	-5.74E+03	4.23E+03	-2090.18	-10631.60	9755.91	3.569
37828	110	-1.88E-01	3.82E+03	1.98E+03	-4.34E+03	7336.61	-1541.25	8216.38	5.620
37743	109	6.25E-02	2.70E+03	6.34E+03	3.30E+03	8291.35	752.80	7941.76	4.858
37795	109	1.88E-01	5.16E+02	5.70E+03	3.24E+03	7258.48	-1045.34	7833.63	5.692
37714	116	6.25E-02	4.65E+03	6.15E+03	-2.73E+03	8236.42	2566.30	7299.82	4.897
37739	115	6.25E-02	2.66E+03	6.36E+03	-2.08E+03	7291.31	1726.87	6599.56	5.662

Table 8.4 Motor Ring to Support Assembly Fastener Minimum Margins (Safe Return)

Motor Ring to Support Assembly - PBAR 501271

FASTENER ID	LOAD CASE	TENSION +PRELOAD ULTIMATE	TENS+BEND +PRELOAD ULTIMATE	SHEAR LOAD	MINIMUM M.S. W/PLD ULTIMATE	MINIMUM BEARING ULTIMATE	MINIMUM SHEAR TEAR-OUT
47701	115	3558.27	3650.07	40.93	0.60	14.25	30.27
47703	116	3557.43	3633.65	17.02	0.60	18.74	39.47

MAXIMUM CONNECTOR TENSION IS 48.98
MAXIMUM CONNECTOR SHEAR IS 94.95

9.0 CONTAINMENT ANALYSIS

For containment analysis, it must be shown that no part can attain sufficient kinetic energy to escape a container, which completely encompasses the part in order to prevent any hazard to the STS/ISS or crew (Ref. SSP 52005B, Section 6.2.1.1). The heaviest mass inside the RC drawer is the compressor, which is about 23.0 lb. In Section 7.0 it is shown that the floating plate, motor mounting ring, power controller module, compressor, and condenser connections are fail-safe. Therefore no containment analysis is necessary for these items. The next heaviest item is the rotor stowed in the stowage drawer. The heaviest rotor has a mass of approximately 4.5 lb.

A containment analysis is performed by assuming that this rotor is released from the stowage drawer and impacts the stowage drawer front panel. The front panel is 0.0625 inch thick. The worst-case net cg acceleration of 4.7g from MPLM Delta Design Cycle Couple Loads Analysis is used in the analysis, which is more conservative than the 1.5g suggested in SSP 52005B. It is assumed that the rotor with a nose radius of 0.5 inch travels 18 inches before it reaches the front panel. Structural containment is demonstrated using the following equation commonly referred to as the "Punch" equation.

$$T_R = \left[\frac{1}{2} * V^2 * \frac{W}{g} * \frac{1}{\pi d Y S w} \right]^{[1/2]}$$

Where,

- TR = Maximum required wall thickness (inches) of the container to prevent escape of the component/part
- W = Weight (pound-force) of the detached piece or part to be contained
- g = Gravitational acceleration (inch per second squared)
- V = Velocity (inches per second) that may be attained by that piece or part
- d = Minimum profile diameter (inches) of piece or part that will produce a shear load on the container wall before escape by any particular piece or part resulting from a structural failure
- YS_W = Yield strength (pound per square inch) of the container wall material

9.0 CONTAINMENT ANALYSIS *Concluded*

Velocity attained by the payload is computed by the following equation:

$$V = \sqrt{2aS_d}$$

Where,

a = Steady state acceleration = 4.7 g

Sd = Maximum travel distance of the rotor = 18 in

$$V = \sqrt{2*4.7*32.2*12*18} = 255.693 \text{ in/sec}$$

The front panel is made of 7075-T7351 Aluminum alloy and has yield strength of 57000 psi. Calculating the required thickness for containment:

$$T_R = \left[\frac{1}{2}*255.693^2*\frac{4.5}{32.2*12}*\frac{1}{\pi*1.0*57000}\right]^{[1/2]}$$

$$T_R = 0.0461 \text{ in}$$

Comparing the computed required thickness (0.0461 in) to the actual thickness of the front panel (0.0625 in), the actual thickness is higher. As a result, no penetration will occur.

10.0 FATIGUE ANALYSIS

Fatigue analysis for the RC is performed using the NASA/FLAGRO, crack growth program. Goddard load spectrum, which is embedded within the NASA/FLAGRO program, is used in the fatigue analysis.

For the RC, the highly loaded element is the front panel flange, which is connected to the other panels is considered for the fatigue analysis. This section is 0.13 inch thick, 2.251 inch wide and has 0.23 inch diameter fastener holes. An initial corner crack size of 0.005 inch is used in this analysis. A tensile stress of 6.862 ksi, a bending stress of 23.359 ksi, and a bearing stress of 14.214 ksi on the front panel flange is used in this analysis.

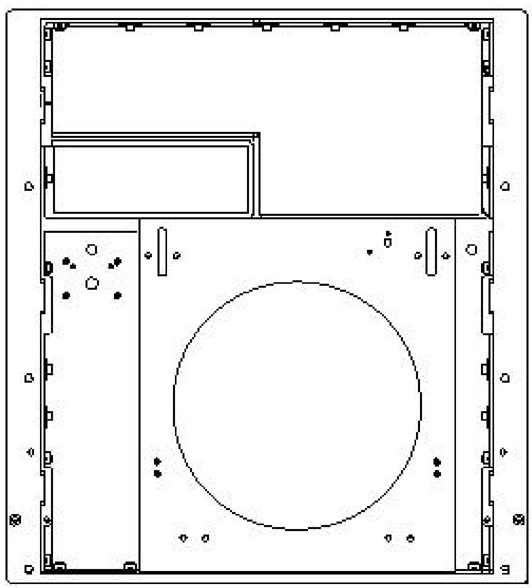
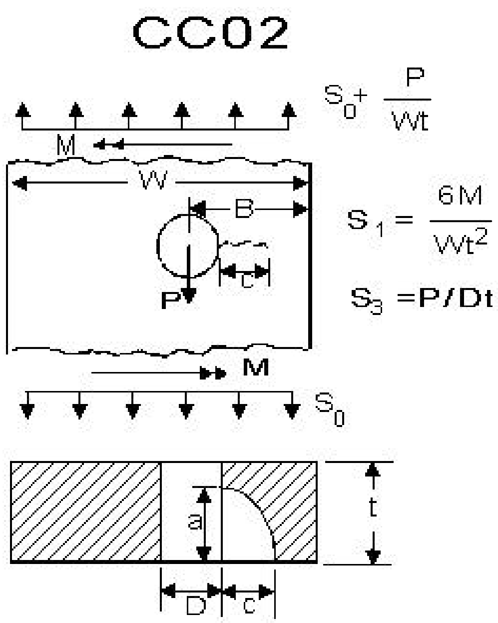


Figure 10-1 RC Front Panel

10.0 <u>FATIGUE ANALYSIS</u> *Concluded*



$W = 2.251$ in

$B = 0.33$ in

$D = 0.23$ in

$t = 0.13$ in

$a = c = 0.005$ in

$S_0 = 6862$ psi

$S_1 = 23359$ psi

$S_3 = 14214$ psi

Figure 10-2 Crack Model

The result of the fatigue analysis is shown in Appendix B. The final fatigue life of the RC after applying a scatter factor of 4.0 is 16 missions.

11.0 DEPRESSURIZATION/REPRESSURIZATION ANALYSIS

For depressurization/repressurization analysis it must be shown that the component can withstand the maximum expected rate of depressurization/repressurization without any structural failure. Following are the depressurization/repressurization rates for MPLM:

Per SSP 57000, Revision D, Section 3.1.1.2:

Depressurization: From 16.0 psi to 0.0 psi at 7.75 psi/min
Repressurization: From 0.0 psi to 16.0 psi at 6.96 psi/min

The maximum internal volume of the RC drawer based on the attached drawing is determined as follows:

Volume, V = 16.41 * 24.0 * 20.269 = 7982.743 in^3

For the purpose of analysis, this value is reduced by 70% to account for volume occupied by internal parts and stowage drawer.

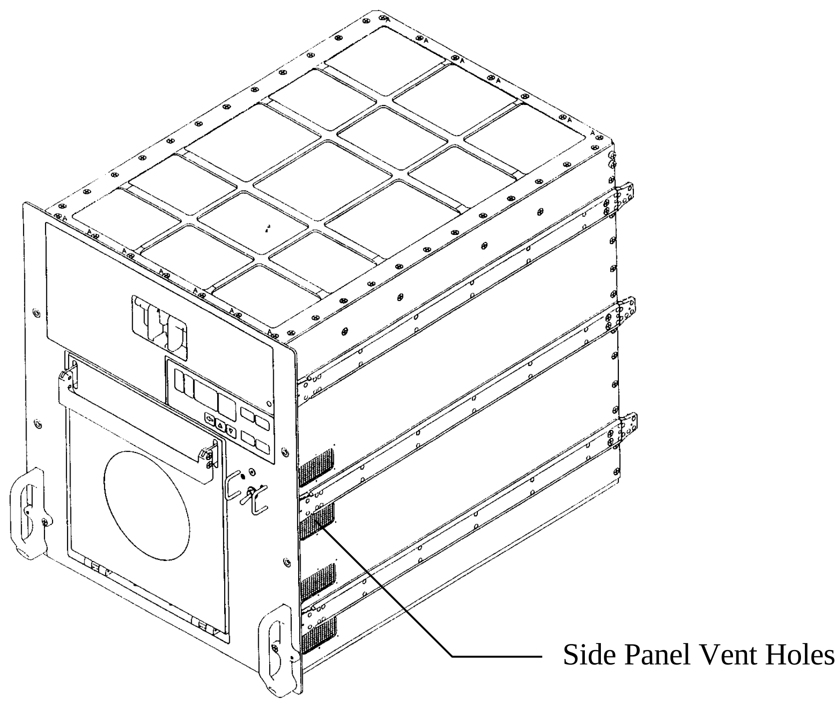


Figure 11-1 Refrigerated Centrifuge

11.0 DEPRESSURIZATION/REPRESSURIZATION ANALYSIS *Continued*

There are four vent holes on each side panels. The total leak area for the RC can be calculated as follows:

Side panel vent hole area = 2.46 * 1.29 = 3.173 in^2

Total side panel vent hole area = 3.174 * 8 = 25.387 in^2

The venting mesh is assumed to block 40% of the available leak area.

There are two fans in the RC drawer. They have outside diameter of 4.35 inch and inside diameter of 1.9 inch.

Fan leak area = $\pi/4\,(4.35^2 - 1.9^2) = 12.026$ in^2

Total fan leak area = 2* 12.026 = 24.053 in^2

It is assumed that the open area of the fan is reduced by 20% due to fan blade blockage.

Analysis is performed using the following orifice equation:

$$dm = dt * A * C_d * \sqrt{2\rho \ \Delta P}$$

Where,

dm = delta mass

dt = time increment

A = leak area

C_d = discharge constant

ρ = air density

P = pressure

And

$$P = \frac{M * R * T}{V}$$

11.0 DEPRESSURIZATION/REPRESSURIZATION ANALYSIS *Continued*

Where,

M = mass of air remaining in the locker
R = gas constant
T = temperature
V = internal volume

For the depressurization case, internal and external pressures are initially assumed to be at the maximum operating pressure and the mass flow is one-way (leaving the RC). For the repressurization case, the internal and external pressures are initially assumed to be zero, mass flow is also one-way (entering the RC), and there is no initial air mass in the locker. By incrementing time and tracking mass flow out of or into the RC, it is possible to calculate the pressure differential between the inside and outside air volumes. The task of performing the iterations was automated with in-house software resulting in a table of RC internal and external pressure, delta pressure, mass inside, and mass discharge versus time. The maximum delta pressure is shown at the bottom of each table. Tables 11.1 through 11.2 are the outputs for the RC worst-case depressurization/repressurization analysis.

Table 11.1 RC Depressurization Output

DEPRESSURIZATION FROM 16.0 PSI TO 0.0 PSI AT 7.75 PSI/MIN.
TOTAL LEAK AREA = 34.4745

TIME (SECS)	PINSIDE	POUTSIDE	PDELTA	MINSIDE	MEXITING
0.0000	16.0000	16.0000	0.00E+00	0.1140	0.00E+00
0.1000	15.9871	15.9871	0.00E+00	0.1139	0.00E+00
0.2000	15.9742	15.9742	0.14E-04	0.1138	0.14E-05
0.3000	15.9613	15.9613	0.00E+00	0.1138	0.00E+00
0.4000	15.9484	15.9484	0.00E+00	0.1137	0.00E+00
0.5000	15.9355	15.9355	0.00E+00	0.1136	0.00E+00
0.6000	15.9226	15.9226	0.00E+00	0.1135	0.00E+00
0.7000	15.9097	15.9097	0.14E-04	0.1134	0.14E-05
0.8000	15.8968	15.8968	0.00E+00	0.1133	0.00E+00
0.9000	15.8839	15.8839	0.00E+00	0.1132	0.00E+00
1.0001	15.8710	15.8710	0.00E+00	0.1131	0.00E+00
1.1001	15.8581	15.8581	0.00E+00	0.1130	0.00E+00
1.2001	15.8452	15.8452	0.00E+00	0.1129	0.00E+00
1.3001	15.8323	15.8323	0.00E+00	0.1128	0.00E+00
1.4001	15.8194	15.8194	0.00E+00	0.1127	0.00E+00
1.5001	15.8065	15.8065	0.00E+00	0.1126	0.00E+00
1.6002	15.7936	15.7936	0.00E+00	0.1126	0.00E+00
1.7002	15.7807	15.7807	0.00E+00	0.1125	0.00E+00
1.8002	15.7678	15.7678	0.00E+00	0.1124	0.00E+00
1.9002	15.7549	15.7549	0.00E+00	0.1123	0.00E+00
2.0002	15.7420	15.7420	0.00E+00	0.1122	0.00E+00
2.1001	15.7291	15.7291	0.00E+00	0.1121	0.00E+00
121.5441	0.3208	0.3208	0.00E+00	0.0023	0.00E+00
121.6433	0.3080	0.3080	0.96E-05	0.0022	0.20E-06
121.7425	0.2952	0.2952	0.80E-05	0.0021	0.20E-06
121.8417	0.2824	0.2824	0.52E-05	0.0020	0.19E-06
121.9408	0.2697	0.2696	0.11E-04	0.0019	0.19E-06
122.0400	0.2569	0.2569	0.37E-04	0.0018	0.18E-06
122.1392	0.2441	0.2441	0.24E-04	0.0017	0.18E-06
122.2384	0.2313	0.2313	0.11E-05	0.0016	0.33E-06
122.3376	0.2185	0.2185	0.28E-04	0.0016	0.17E-06
122.4367	0.2057	0.2057	0.00E+00	0.0015	0.00E+00
122.5359	0.1929	0.1929	0.28E-04	0.0014	0.16E-06
122.6351	0.1801	0.1801	0.00E+00	0.0013	0.00E+00
122.7343	0.1673	0.1673	0.00E+00	0.0012	0.00E+00
122.8335	0.1545	0.1545	0.00E+00	0.0011	0.00E+00
122.9327	0.1417	0.1417	0.80E-05	0.0010	0.14E-06
123.0318	0.1289	0.1289	0.10E-06	0.0009	0.18E-06
123.1310	0.1161	0.1161	0.47E-05	0.0008	0.19E-06
123.2302	0.1033	0.1033	0.00E+00	0.0007	0.00E+00
123.3294	0.0905	0.0905	0.14E-04	0.0006	0.11E-06
123.4286	0.0777	0.0777	0.25E-06	0.0006	0.11E-06
123.5277	0.0649	0.0649	0.49E-06	0.0005	0.93E-07
123.6269	0.0521	0.0521	0.37E-05	0.0004	0.92E-07
123.7261	0.0394	0.0393	0.90E-05	0.0003	0.92E-07
123.8253	0.0266	0.0266	0.19E-04	0.0002	0.92E-07

```
 123.9245   0.0138   0.0138   0.48E-04  0.0001    0.91E-07
 124.0237   0.0014   0.0010   0.42E-03  0.0000    0.77E-07

MAXIMUM DELTA PRESSURE = 4.18463E-04
TIME = 124.0237
```

Table 11.2 RC Repressurization Output

REPRESSURIZATION FROM 0.0 PSI TO 16.0 PSI AT 6.96 PSI/MIN.

TOTAL LEAK AREA = 34.4745

TIME (SECS)	PINSIDE	POUTSIDE	PDELTA	MINSIDE	MEXITING
0.0000	0.0000	0.0000	0.00E+00	0.0000	0.00E+00
0.1000	0.0115	0.0116	0.49E-04	0.0001	0.83E-07
0.2000	0.0232	0.0232	0.18E-04	0.0002	0.83E-07
0.3000	0.0348	0.0348	0.84E-05	0.0002	0.83E-07
0.4000	0.0464	0.0464	0.34E-05	0.0003	0.83E-07
0.5000	0.0580	0.0580	0.40E-06	0.0004	0.83E-07
0.6000	0.0696	0.0696	0.19E-06	0.0005	0.97E-07
0.7000	0.0812	0.0812	0.49E-05	0.0006	0.14E-06
0.8000	0.0928	0.0928	0.00E+00	0.0007	0.00E+00
0.9000	0.1044	0.1044	0.42E-05	0.0007	0.17E-06
1.0001	0.1160	0.1160	0.11E-04	0.0008	0.12E-06
1.1001	0.1276	0.1276	0.00E+00	0.0009	0.00E+00
1.2001	0.1392	0.1392	0.12E-04	0.0010	0.13E-06
1.3001	0.1508	0.1508	0.11E-04	0.0011	0.13E-06
1.4001	0.1624	0.1624	0.00E+00	0.0012	0.00E+00
1.5001	0.1740	0.1740	0.00E+00	0.0012	0.00E+00
1.6002	0.1856	0.1856	0.00E+00	0.0013	0.00E+00
1.7002	0.1972	0.1972	0.00E+00	0.0014	0.00E+00
1.8002	0.2088	0.2088	0.00E+00	0.0015	0.00E+00
1.9002	0.2204	0.2204	0.00E+00	0.0016	0.00E+00
2.0002	0.2320	0.2320	0.00E+00	0.0017	0.00E+00
2.1001	0.2436	0.2436	0.33E-05	0.0017	0.17E-06
2.2000	0.2552	0.2552	0.27E-05	0.0018	0.17E-06
2.2999	0.2668	0.2668	0.21E-05	0.0019	0.17E-06
2.3998	0.2784	0.2784	0.00E+00	0.0020	0.00E+00
135.4671	15.7142	15.7142	0.86E-05	0.1120	0.14E-05
135.5739	15.7265	15.7266	0.86E-05	0.1121	0.14E-05
135.6807	15.7389	15.7389	0.38E-05	0.1122	0.14E-05
135.7875	15.7513	15.7513	0.76E-05	0.1123	0.14E-05
135.8943	15.7637	15.7637	0.38E-05	0.1123	0.14E-05
136.0011	15.7761	15.7761	0.76E-05	0.1124	0.14E-05
136.1079	15.7885	15.7885	0.95E-05	0.1125	0.14E-05
136.2147	15.8009	15.8009	0.12E-04	0.1126	0.14E-05
136.3215	15.8133	15.8133	0.00E+00	0.1127	0.00E+00
136.4284	15.8257	15.8257	0.00E+00	0.1128	0.00E+00
136.5352	15.8381	15.8381	0.00E+00	0.1129	0.00E+00
136.6420	15.8505	15.8505	0.00E+00	0.1130	0.00E+00
136.7488	15.8628	15.8628	0.00E+00	0.1130	0.00E+00
136.8556	15.8752	15.8752	0.00E+00	0.1131	0.00E+00
136.9624	15.8876	15.8876	0.00E+00	0.1132	0.00E+00
137.0692	15.9000	15.9000	0.00E+00	0.1133	0.00E+00
137.1760	15.9124	15.9124	0.00E+00	0.1134	0.00E+00
137.2829	15.9248	15.9248	0.00E+00	0.1135	0.00E+00
137.3897	15.9372	15.9372	0.00E+00	0.1136	0.00E+00
137.4965	15.9496	15.9496	0.48E-05	0.1137	0.14E-05
137.6033	15.9620	15.9620	0.00E+00	0.1138	0.00E+00
137.7101	15.9744	15.9744	0.00E+00	0.1138	0.00E+00

```
 137.8169  15.9867  15.9867   0.00E+00  0.1139    0.00E+00
 137.9237  15.9991  15.9991   0.00E+00  0.1140    0.00E+00

MAXIMUM DELTA PRESSURE = 4.92968E-05
TIME = 0.100001
```

11.0 DEPRESSURIZATION/REPRESSURIZATION ANALYSIS *Concluded*

For the depressurization/repressurization rate specified, the maximum delta pressure experienced is negligible (0.00042 psi). In other words, the leak area is sufficient to prevent significant delta pressure build-up during depressurization or repressurization event. If this pressure is applied to the top panel (the thinnest and the largest area panel), which has an area of 401 in^2, the force imparted is only 0.168 lb. As a result, it can be stated that the effect of depressurization/repressurization is negligible.

12.0 FRACTURE CONTROL

Fracture control for the Refrigerated Centrifuge will be addressed in a separate document.

13.0 SUMMARY

Stress analysis of the RC, P/N SED46117400-301 for the International Space Station program is completed. A weight of 158.532 lb is used in the analysis of the RC. Analysis results show that all the structural members of the RC Assembly are capable of withstanding MPLM loads. The quasi-static load factors and the random vibration environment are obtained from SSP 57000, Rev. D and the random loads factors are computed based on mass participation method. System frequencies obtained from normal mode analysis of the RC FEM are used in the random vibration load factor computation.

Crew induced loads analysis, fail-safe analysis, safe return configuration analysis, containment analysis, fatigue analysis, and depressurization/repressurization analysis are also performed and the hardware is shown to be capable of withstanding these types of loads without failure.

Positive margins of safety have been obtained for all structural members of the RC. The RC meets all the structural and structural safety requirements stated in the Structural Verification Plan for HRF Payloads and Racks, LS-71012. The RC has a fatigue life of 16 missions. The RC is structurally qualified for flight in MPLM or any subsequent mission where analysis loads and weight do not exceed the values used in this report.

Analysis of the RC will be completed when the integrated Rack-level analysis is performed.

APPENDIX A

MATERIAL, FASTENER AND FAN SPECIFICATIONS

Table 3.6.2.0(b$_2$). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Plate

Specification	AMS 4026 and AMS-QQ-A-250/11				AMS-QQ-A-250/11		AMS 4025, AMS 4027 and AMS-QQ-A-250/11					
Form	Plate											
Temper	T451				T42[a]		T651 and T62[b]					
Thickness, in.	0.250-2.000		2.001-3.000		0.250-1.000	1.001-3.000	0.250-2.000		2.001-3.000		3.001-4.000	4.001-6.000[d]
Basis	A	B	A	B	S	S	A	B	A	B	S	S
Mechanical Properties:												
F_{tu}, ksi:												
L	...	...	...	...	...	...	42	43	...	...	...	...
LT	30	32	30	32	30	30	42	43	42	43	42	40
F_{ty}, ksi:												
L	...	...	...	...	...	...	36	38	...	...	...	...
LT	16	18	16	18	14	14	35	37	35	37	35	35
F_{cy}, ksi:												
L	...	...	...	...	...	...	35	37	...	...	...	...
LT	16	18	...	...	...	...	36	38	...	...	...	...
F_{su}, ksi	20	21	...	...	...	...	27	28	...	...	...	...
F_{bru}, ksi:												
(e/D = 1.5)	48	51	...	...	...	...	67	69	...	...	...	...
(e/D = 2.0)	63	67	...	...	...	...	88	90	...	...	...	...
F_{bry}, ksi:												
(e/D = 1.5)	22	25	...	...	...	...	50	53	...	...	...	...
(e/D = 2.0)	26	29	...	...	...	...	58	61	...	...	...	...
e, percent (S-basis):												
LT	[c]	...	16	...	18	16	[c]	...	6	...	6	6
E, 10^3 ksi	9.9											
E_c, 10^3 ksi	10.1											
G, 10^3 ksi	3.8											
μ	0.33											
Physical Properties:												
ω, lb/in.^{3}	0.098											
C, K, and α	See Figure 3.6.2.0											

a Design allowables were based upon data obtained from testing samples of material, supplied in the O temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.

b Design allowables were based upon data obtained from testing T651 plate and from testing samples of plate, supplied in the O temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained may be lower than those listed if the material has been formed or otherwise cold worked, particularly in the annealed temper, prior to solution heat treatment.

c See Table 3.6.2.0(b$_3$).

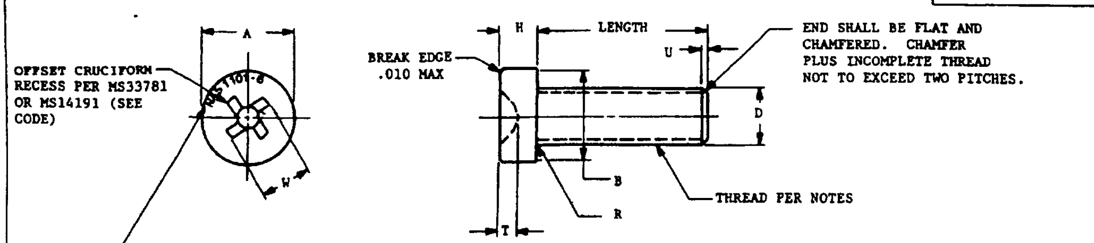
d Properties for this thickness apply only to T651 temper.

Table 3.7.4.0(b$_3$). Design Mechanical and Physical Properties of 7075 Aluminum Alloy Sheet and Plate—Continued

Specification	AMS-QQ-A-250/12	AMS 4078 and AMS-QQ-A-250/12													
Form	Sheet	Plate													
Temper	T73	T7351													
Thickness, in.	0.040-0.249	0.250-0.499	0.500-1.000		1.001-1.500		1.501-2.000		2.001-2.500		2.501-3.000		3.001-3.500	3.501-4.000
Basis	S	S	A	B	A	B	A	B	A	B	A	B	S	S
Mechanical Properties:														
F_{tu}, ksi:														
L	67	68	68	70	67	69	66	68	65	67	63	65	62	60
LT	67	69	69	71	68	70	67	69	66	68	64[c]	66	63	61
ST	...	...	...	...	...	...	63	65	62	64	60	62	59	57
F_{ty}, ksi:														
L	56	57	57	59	57	59	55	57	52	55	49	53	49	48
LT	56	57	57	59	57	59	55	57	52[b]	55	49[c]	53	49	48
ST	...	...	...	...	...	...	52	54	49	52	47	50	47	46
F_{cy}, ksi:														
L	55	56	56	58	56	58	53	55	50	53	47	51	47	45
LT	58	59	59	61	59	61	57	59	54	57	51	55	51	50
ST	...	...	...	...	...	...	59	61	55	58	51	55	50	48
F_{su}, ksi	38	38	38	39	38	40	39	40	39	40	38	39	38	37
F_{bru}[a], ksi:														
(e/D = 1.5)	105	102	103	106	103	106	102	106	102	105	100	103	99	96
(e/D = 2.0)	134	131	132	136	132	136	132	136	131	135	128	132	127	124
F_{bry}[a], ksi:														
(e/D = 1.5)	84	79	81	83	83	86	82	85	79	83	76	81	76	76
(e/D = 2.0)	102	95	97	100	99	102	97	101	93	99	89	96	89	88
e, percent (S-basis):														
LT	8	7	7	...	6	...	6	...	6	...	6	...	6	6
E, 10^3 ksi	10.3	10.3												
E_c, 10^3 ksi	10.5	10.6												
G, 10^3 ksi	3.9	3.9												
μ	0.33	0.33												
Physical Properties:														
ω, lb/in.^{3}	0.101													
C, K, and α	See Figure 3.7.4.0													

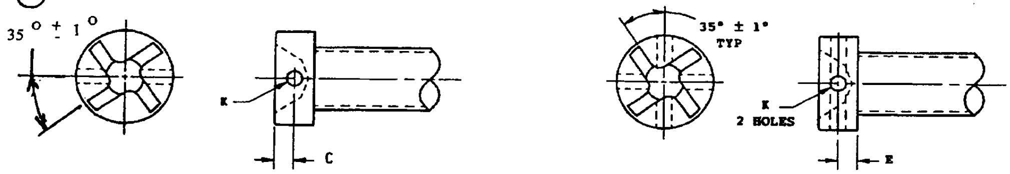
a Bearing values are "dry pin" values per Section 1.4.7.1. See Table 3.1.2.1.1.
b S-basis. The rounded T_{99} value is as follows: F_{ty}(LT) = 53 ksi.
c S-basis. The rounded T_{99} values are as follows: F_{tu}(LT) = 65 ksi and F_{ty}(LT) = 52 ksi.

FED. SUP CLASS 5305



HEAD MARKING: BASIC PART NUMBER, MANUFACTURER'S TRADEMARK, AND FIRST DASH NUMBER ON SIZES 3 AND LARGER. FIRST DASH NUMBER ONLY ON SIZES 04, 06, AND 08. NO MARKING REQUIRED ON SIZES 00, 01, AND 02. MARK MATERIAL PER CODE TO INDICATE CRES OR TITANIUM WHERE APPLICABLE. RAISED OR DEPRESSED .010 MAX. LOCATION OPTIONAL. WHERE APPLICABLE, ADD "R" AFTER FIRST DASH NUMBER ON SIZES 06, 08, 3, 4, AND 5 TO INDICATE MS14191 RECESS.

(10)



DRILLED HEAD (CODE B) CROSS-DRILLED HEAD (CODE D)

(10)

PART NUMBER	THREAD SEE THD NOTE (n)	A DIA	B DIA MIN	C REF	E	K DIA	H	R RAD	D DIA MAX	U REF	T MAX	W MAX	RECESS GAGE PENETRATION (c) MAX	RECESS GAGE PENETRATION (c) MIN	MIN TENSILE STRENGTH, LBS (t)
NAS1101-00	.0600-80 UNJF-3A	.096 .092	.082				.037 .029	.010 .005	.060	.010	.033	.087	.0250	.0170	288
NAS1101-01	.0730-64 UNJC-3A	.118 .114	.104				.045 .037	.010 .005	.073	.010	.039	.104	.0300	.0215	420
NAS1101-02	.0860-56 UNJC-3A	.140 .136	.126				.053 .044	.010 .005	.086	.010	.046	.122	.0350	.0260	591
NAS1101-04	.1120-40 UNJC-3A	.183 .178	.168	.034	.035 .030	(r)	.069 .059	.010 .005	.112	.013	.059	.157	.0450	.0350	966
NAS1101-06	.1380-32 UNJC-3A	.226 .221	.211	.044	.045 .035	.042 .034	.086 .074	.010 .005	.138	.016	.072	.193	.0555	.0450	1,450
NAS1101-08	.1640-32 UNJC-3A	.270 .265	.255	.049	.050 .040	.042 .034	.102 .088	.020 .010	.164	.016	.085	.228	.0660	.0545	2,240
NAS1101-3	.1900-32 UNJF-3A	.313 .306	.296	.056	.060 .050	.042 .034	.118 .103	.020 .010	.190	.016	.098	.263	.0760	.0635	3,180
NAS1101-4	.2500-28 UNJF-3A	.375 .367	.357	.075	.080 .070	.068 .060	.150 .133	.020 .010	.250	.018	.128	.345	.0990	.0850	5,820
NAS1101-5	.3125-24 UNJF-3A	.438 .429	.413	.094	.090 .080	.068 .060	.183 .162	.020 .010	.312	.021	.134	.382	.0985	.0825	9,200
NAS1101-6	.3750-24 UNJF-3A	.563 .552	.536	.113	.100 .090	.068 .060	.215 .191	.025 .015	.375	.021	.161	.457	.1180	.1000	14,000

Procurement Specification: MIL-B-87114, except as noted. Tensile load values as tabulated herein. Cold working head to shank fillet and fatigue requirements are not applicable.

(10)

LIST OF CURRENT SHEETS

SHT.	REV.
1	10
2	10
3	NEW

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
1250 EYE STREET, N.W.
WASHINGTON, D.C. 20005

THIS DRAWING SUPERSEDES ALL ANTECEDENT STANDARD DRAWINGS FOR THE SAME PRODUCT AND SHALL BECOME EFFECTIVE NO LATER THAN SIX MONTHS FROM THE LAST DATE OF APPROVAL SHOWN HEREON.

APPROVAL DATE JUNE 1958

REVISION (10) 5 Dec. 1996

CUSTODIAN NATIONAL AEROSPACE STANDARDS COMMITTEE

THIRD ANGLE PROJECTION

PROCUREMENT SPECIFICATION NOTED

TITLE

SCREW, MACHINE-FLAT FILLISTER HEAD, FULL THREAD, OFFSET CRUCIFORM

CLASSIFICATION STANDARD PART

NAS 1101 (10)

SHEET 1 OF 3

Aerospace Industries Association

NATIONAL AEROSPACE STANDARD

LENGTH CHART					
TOLERANCE	+.000 -.031	TOLERANCE	+.000 -.062	TOLERANCE	+.000 -.094
DASH NO.	LENGTH	DASH NO.	LENGTH	DASH NO.	LENGTH
3	.188	18	1.125	34 TO 96	2.125 TO 6.000
4	.250	20	1.250		
5	.312	22	1.375		
6	.375	24	1.500		
7	.438	26	1.625		
8	.500	28	1.750		
10	.625	30	1.875		
12	.750	32	2.000		
14	.875				
16	1.000				

(10) MATERIAL: Alloy steel - 4140 (UNS G41400) per MIL-S-5626, 4340 (UNS G43400) per AMS6415, E4340 (UNS G43406) per MIL-S-5000 or 8740 (UNS G87400) per MIL-S-6049.
Cres - A286 (UNS S66286) conforming to the chemistry of AMS5731, AMS5732, AMS5737 or AMS5853.
Titanium Alloy - 6AL-4V (UNS R56400) per AMS4928 or AMS4967.

(10) HEAT TREAT: Develop basic material properties as follows; with controls per MIL-H-6875.
Alloy steel: 160-180 KSI Ftu per MIL-H-6875.
Cres: 160-190 KSI Ftu. Precipitation hardening per AMS5853. (t)
Titanium alloy: 160-180 KSI Ftu per AMS4928 or AMS4967.

FINISH: Alloy steel - Cadmium plate per QQ-P-416, Type II, Class 2 (no code) or cadmium plate per QQ-P-416, Type II, Class 2 with dull black chromate treatment (B code).
(10) Cres - Clean and passivate in accordance with QQ-P-35 (no code) or cadmium plate per QQ-P-416, Type II, Class 2 (P code). Post-plate hydrogen embrittlement baking and testing per QQ-P-416 are not required for A286 material.
Titanium alloy - None (no code) or aluminum coat per NAS4006 (A code) or aluminum coat per MIL-C-83488, Type II, Class 3 (C code) ~~or cadmium plate per QQ-P-416, Type II, Class 2 (P code).~~

CODE: First dash number designates diameter and thread.
Second dash number indicates length in .0625 increments (as converted to three decimal places per ANSI Y14.5).
Intermediate or longer lengths may be specified by use of whole dash numbers only.
Use of .25 inch increments is recommended for screws over 3 inches long.
"A" following last dash number designates aluminum coat per NAS4006.
"B" following last dash number designates dull black cadmium plate.
"C" following last dash number designates aluminum coat per MIL-C-83488, Type II, Class 3.
"D" in lieu of second dash designates cross-drilled head.
"E" in lieu of first dash designates cres.
"H" in lieu of second dash designates drilled head.
"P" following last dash number designates cadmium plate per QQ-P-416, Type II, Class 2.
"V" in lieu of first dash designates titanium alloy.
~~"W" following last dash number designates Type I plating.~~ (q)

EXAMPLE: NAS1101-3-8 = .1900-32 screw, .500 length, alloy steel, MS33781 recess, Type II plating.
NAS1101-5-10B = .3125-24 screw, .625 length, alloy steel, dull black cadmium plating, MS33781 recess.
NAS1101E5-10P = .3125-24 screw, .625 length, cres, MS33781 recess, Type II plating.
NAS1101V5-10 = .3125-24 screw, .625 length, titanium alloy, MS33781 recess.
NAS1101V5HR10 = .3125-24 screw, .625 length, titanium alloy, drilled head, MS14191 recess.

THIS DRAWING SUPERSEDES ALL ANTECEDENT STANDARD DRAWINGS FOR THE SAME PRODUCT AND SHALL BECOME EFFECTIVE NO LATER THAN SIX MONTHS FROM THE LAST DATE OF APPROVAL SHOWN HEREON.

APPROVAL DATE JUNE 1958 REVISION (10) 5 Dec. 1996

NAS 1101 SHEET 2

NOTES: (a) Diameter of unthreaded portion of screws shall not be less than minimum pitch diameter nor more than maximum major diameter of thread.

(b) For screws 2 inches long or shorter, complete threads shall extend to within 2 threads of the bearing surface of the head. Screws of longer length shall have a minimum complete thread length of 1.750 inches.

(c) Recess gaging in accordance with MS33781 or MS14191 as applicable.

(d) Screws shall be free from burrs and sharp edges.

(e) Offset cruciform screws to be installed and removed with drivers per MS33781 or MS14191 as applicable.

(f) Bearing surface squareness: within .003 FIM of shank dia.

(g) For cres, magnetic permeability shall be less than 2.0 (Air = 1.0) for field strength H = 200 Oersteds. (Magnetic permeability indicator per ASTM A342.)

(h) Tensile stress areas used for calculation of ultimate tensile strength values are based on FED-STD-H28.

(k) For description of status notes, see NAS380.

(l) Dimensions are in inches and apply after plating and coating.

(m) Surface roughness: "D" dia. underside of head and sides and root of threads - 32 microinches, other surfaces - 125 microinches, per ANSI/ASME B46.1.

(n) Threads in accordance with MIL-S-8879.

(p) MS14191 recess is applicable to sizes 06 thru 5 inclusive; MS33781 recess is applicable to all sizes.

(q) Type I plating ("W" code) is inactive for new design.

(r) For the drilled head (H code), diameter K is .034 to .042. For the cross-drilled head (D code), diameter K is .022 to .030.

(t) The effect of cold work and aging induced during the manufacturing cycle may increase the ultimate tensile value of the finished part, but this shall not exceed 1.3 times the specified minimum tensile value.

APPROVAL DATE Dec. 1996 REVISION

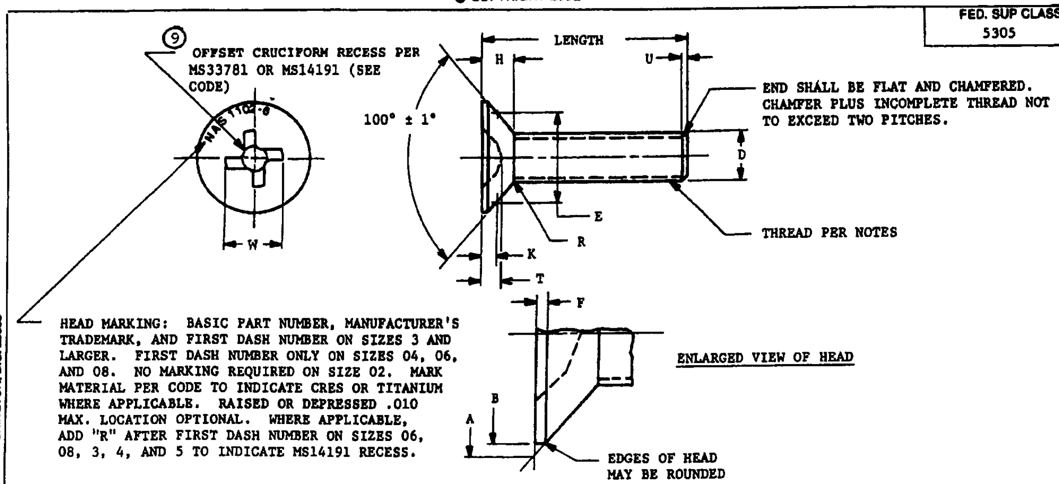
Aerospace Industries Association

NATIONAL AEROSPACE STANDARD

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
1250 EYE STREET, N.W.
WASHINGTON, D.C. 20005

APPROVAL DATE JUNE 1958 REVISION 1 31 JAN 1960 2 15 NOV 1960 3 31 MAY 1965 4 31 MAY 1968 5 5 JUNE 1971 6 15 FEB 1973 7 28 MAY 1982 8 15 MAY 1986 9 9 OCTOBER 1991

FED. SUP CLASS
5305



PART NUMBER	THREAD SEE THD NOTE (1)	A DIA	B ABSOLUTE MIN DIA	F	H REF	R	U REF	D DIA MAX	T MAX	W MAX	RECESS GAGE PENETRATION (c) MAX	RECESS GAGE PENETRATION (c) MIN	K	E DIA
NAS1102-02	.0860-56 UNJC-3A	.172 .162	.126	.015 .005	.036	.015 .005	.010	.086	.043	.115	.0315	.0225		
NAS1102-04	.1120-40 UNJC-3A	.225 .213	.177	.015 .005	.045	.015 .005	.013	.112	.055	.148	.0405	.0305		
NAS1102-06	.1380-32 UNJC-3A	.279 .267	.231	.015 .005	.057	.020 .010	.016	.138	.066	.182	.0500	.0395		
NAS1102-08	.1640-32 UNJC-3A	.332 .319	.270	.020 .010	.068	.020 .010	.016	.164	.078	.215	.0595	.0480	.0268 .0240	.2671 .2667
NAS1102-3	.1900-32 UNJF-3A	.385 .371	.322	.020 .010	.080	.020 .010	.016	.190	.090	.248	.0685	.0560	.0290 .0263	.3147 .3143
NAS1102-4	.2500-28 UNJF-3A	.507 .491	.442	.020 .010	.106	.020 .010	.018	.250	.118	.325	.0890	.0750	.0342 .0316	.4245 .4241
NAS1102-5	.3125-24 UNJF-3A	.635 .617	.568	.020 .010	.133	.020 .010	.021	.312	.122	.357	.0860	.0700	.0395 .0370	.5389 .5385
NAS1102-6	.3750-24 UNJF-3A	.762 .742	.694	.020 .010	.160	.020 .010	.021	.375	.145	.427	.1030	.0850	.0450 .0426	.6532 .6528

MATERIAL: 9 Alloy steel - 4140 (UNS G41400) per MIL-S-5626, 4340 (UNS G43400) per MIL-S-5000, or 8740 (UNS G87400) per MIL-S-6049.
Cres - A286 (UNS S66286) per AMS5737 , except for heat treatment.
Titanium alloy - 6AL-4V (UNS R56400) per AMS4967.

HEAT TREATMENT: Alloy steel - 160,000-180,000 PSI UTS per MIL-H-6875.
Cres - 160,000 PSI UTS min. at room temperature.
Titanium alloy - 160,000 PSI UTS min.

FINISH: 9 Alloy steel - Cadmium plate per QQ-P-416, Type II, Class 2 (no code) or cadmium plate per QQ-P-416, Type II, Class 2 with dull black chromate treatment (B code).
Cres - clean and passivate in accordance with QQ-P-35 (no code) or cadmium plate per QQ-P-416, Type II, Class 2 (P code).
Titanium alloy - none (no code) or aluminum coat per NAS4006 (A code) or aluminum coat per MIL-C-83488, Type II, Class 3 (C code) ~~or cadmium plate per QQ-P-416, Type II, Class 2 (P code).~~

THIS DRAWING SUPERSEDES ALL ANTECEDENT STANDARD DRAWINGS FOR THE SAME PRODUCT AND SHALL BECOME EFFECTIVE NO LATER THAN SIX MONTHS FROM THE LAST DATE OF APPROVAL SHOWN HEREON.

LIST OF CURRENT SHEETS

NO.	REV.
1	9
2	8

CUSTODIAN	NATIONAL AEROSPACE STANDARDS COMMITTEE	THIRD ANGLE PROJECTION
PROCUREMENT SPECIFICATION NOTED	TITLE **SCREW, MACHINE-FLAT 100 DEG HEAD FULL THREAD, OFFSET CRUCIFORM** 9	CLASSIFICATION STANDARD PART **NAS 1102** SHEET 1 OF 2

NATIONAL AEROSPACE STANDARD

LENGTH CHART					
TOLERANCE +.000 -.031		TOLERANCE +.000 -.062		TOLERANCE +.000 -.094	
DASH NO.	LENGTH	DASH NO.	LENGTH	DASH NO.	LENGTH
3	.188	18	1.125	34 to 96	2.125 to 6.000
4	.250	20	1.250		
5	.312	22	1.375		
6	.375	24	1.500		
7	.438	26	1.625		
8	.500	28	1.750		
10	.625	30	1.875		
12	.750	32	2.000		
14	.875				
16	1.000				

MIN TENSILE STRENGTH, LBS	
PART NUMBER	ALLOY STEEL CRES (160KSI) TI (6AL-4V)
NAS1102-02	591
NAS1102-04	966
NAS1102-06	1,450
NAS1102-08	2,240
NAS1102-3	3,180
NAS1102-4	5,820
NAS1102-5	9,200
NAS1102-6	14,000

CODE: First dash number designates diameter and thread.
Second dash number indicates length in .0625 increments (as converted to three decimal places per ANSI Y14.5).
Intermediate or longer lengths may be specified by use of whole dash numbers only.
Use of .25 inch increments is recommended for screws over 3 inches long.
"A" following last dash number designates aluminum coat per NAS4006.
8 "B" following last dash number designates dull black cadmium plating.
8 "C" following last dash number designates aluminum coat per MIL-C-83488, Type II, Class 3.
"E" in lieu of first dash designates cres.
8 "P" following last dash number designates cadmium plate per per QQ-P-416, Type II, Class 2.
"R" in lieu of second dash designates recess per MS14191 for sizes 06 thru 5 inclusive.
"V" in lieu of first dash designates titanium alloy.
8 ~~"W" following last dash number designates Type I plating~~. (q)

EXAMPLE: NAS1102-3-8 = .1900-32 screw, .500 length, alloy steel, MS33781 recess, Type II plating.
8 NAS1102E5-10P = .3125-24 screw, .625 length, cres, MS33781 recess, Type II plating
NAS1102V5R10 = .3125-24 screw, .625 length, titanium alloy, MS14191 recess.
8 NAS1102-5-10B = .3125-24 screw, .625 length, alloy steel, MS33781 recess, dull black cadmium plating.

NOTES:
(a) Diameter of unthreaded portion of screws shall not be less than minimum pitch diameter nor more than maximum major diameter of thread.
(b) For screws 2 inches long or shorter, complete threads shall extend to within 2 threads of the bearing surface of the head. Screws of longer length shall have a minimum complete thread length of 1.750 inches.
(c) Recess gaging in accordance with MS33781 or MS14191 as applicable, refer to NAS518 and NAS519 for flushness gaging details.
(d) Screws shall be free from burrs and sharp edges.
8 (e) Offset cruciform screws to be installed and removed with drivers per MS33781 or MS14191 as applicable.
(f) Concentricity: Conical surface of head and pitch dia. of screw within .005 TIR.
(g) For cres, magnetic permeability shall be less than 2.0 (Air = 1.0) for a field strength H = 200 Oersteds. (Magnetic permeability indicator per MIL-1-17214.)
(h) Tensile stress areas used for calculation of ultimate tensile strength values are based on FED-STD-H28.
(k) For description of status notes, see NAS380.
(l) Threads in accordance with MIL-S-8879.
(m) Surface roughness: "D" dia., underside or head, and sides and root of threads - 32 microinches, other surfaces - 125 microinches, per ANSI B46.1.
8 (n) Dimensions are in inches and apply after plating and coating.
(p) MS14191 recess is applicable to sizes 06 thru 5 inclusive. MS33781 recess is applicable to all sizes.
(q) Type I plating ("W" code) is inactive for new design.

PROCUREMENT SPECIFICATION: MIL-B-87114, except as noted. Tensile load values as tabulated herein. Cold working head to shank fillet and fatigue requirements are not applicable.

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
1250 EYE STREET, N.W.
WASHINGTON, D.C. 20005

THIS DRAWING SUPERSEDES ALL ANTECEDENT STANDARD DRAWINGS FOR THE SAME PRODUCT AND SHALL BECOME EFFECTIVE NO LATER THAN SIX MONTHS FROM THE LAST DATE OF APPROVAL SHOWN HEREON.

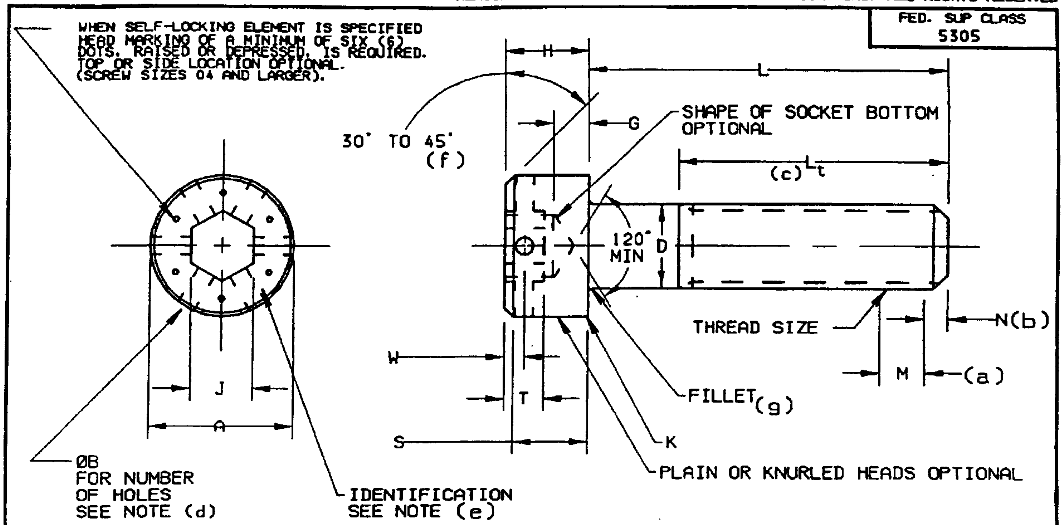
APPROVAL DATE JUNE 1985 REVISION 1 31 MARCH 1960 2 15 NOV 1960 3 31 MAY 1965 4 31 MAY 1968 5 15 JUNE 1971 6 28 MAY 1982 7 15 MAY 1986 8 9 OCTOBER 1991

NAS 1102 SHEET 2

Aerospace Industries Association

NATIONAL AEROSPACE STANDARD

FED. SUP CLASS 5305



NOMINAL SIZE DASH NO.	THREAD SIZE	D BODY DIAMETER		A HEAD DIAMETER		H HEAD HEIGHT		S HEAD SIDE HEIGHT MIN.	J SOCKET SIZE	T KEY ENGAGEMENT MIN	G WALL THICKNESS MIN.	K CHAMFER OR RADIUS MAX.
		MAX.	MIN.	MAX.	MIN.	MAX.	MIN.		NOMINAL			
00	.0600-80	.060	.0568	.096	.091	.060	.057	.054	.050	.025	.020	.003
01	.0730-72	.073	.0695	.118	.112	.073	.070	.066	.062	.031	.025	.003
02	.0860-64	.086	.0822	.140	.134	.086	.083	.077	.078	.038	.029	.003
03	.0990-56	.099	.0949	.161	.154	.099	.095	.089	.078	.044	.034	.003
04	.1120-48	.112	.1075	.183	.176	.112	.108	.101	.094	.051	.038	.005
06	.1380-40	.138	.1329	.226	.218	.138	.134	.124	.109	.064	.047	.005
08	.1640-36	.164	.1585	.270	.262	.164	.159	.148	.141	.077	.056	.005
3	.1900-32	.190	.1840	.312	.303	.190	.185	.171	.156	.090	.065	.005
4	.2500-28	.250	.2435	.375	.365	.250	.244	.225	.188	.120	.095	.008
5	.3125-24	.3125	.3053	.469	.457	.312	.306	.281	.250	.151	.119	.008
6	.3750-24	.375	.3678	.562	.550	.375	.368	.337	.312	.182	.143	.008
7	.4375-20	.4375	.4294	.656	.642	.437	.430	.394	.375	.213	.166	.010
8	.5000-20	.500	.4919	.750	.735	.500	.492	.450	.375	.245	.190	.010
10	.6250-18	.625	.6163	.937	.921	.625	.616	.562	.500	.307	.238	.010
12	.7500-16	.750	.7406	1.125	1.107	.750	.740	.675	.625	.370	.285	.010
14	.8750-14	.875	.8647	1.312	1.293	.875	.864	.787	.750	.432	.333	.015
16	1.0000-12	1.000	.9886	1.500	1.479	1.000	.988	.900	.750	.495	.380	.015

LIST OF CURRENT SHEETS

NO.	REV.
1	9
2	4
3	9
4	1

(9) COMPLETELY REVISED

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC. 1250 EYE STREET, N.W. WASHINGTON, D.C. 20005

THIS DRAWING SUPERSEDES ALL ANTECEDENT STANDARD DRAWINGS FOR THE SAME PRODUCT AND SHALL BECOME EFFECTIVE NO LATER THAN SIX MONTHS FROM THE LAST DATE OF APPROVAL SHOWN HEREON.

REVISION (9) 31 May 1996

APPROVAL DATE: APRIL 1962

CUSTODIAN NATIONAL AEROSPACE STANDARDS COMMITTEE

THIRD ANGLE PROJECTION

PROCUREMENT SPECIFICATION: NOTED

TITLE: SCREW, CAP, SOCKET HEAD UNDRILLED AND DRILLED, PLAIN AND SELF-LOCKING ALLOY STEEL, CORROSION-RESISTANT STEEL AND HEAT-RESISTANT STEEL, UNRF-3A

CLASSIFICATION: PART STANDARD

NAS 1351
SHEET 1 OF 4

Aerospace Industries Association

NATIONAL AEROSPACE STANDARD

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
1250 EYE STREET, N.W.
WASHINGTON, D.C. 20005

NOMINAL SIZE DASH NO.	Lt MINIMUM BASIC THREAD LENGTH (c)	SAFETY WIRE HOLE WHEN SPECIFIED				MINIMUM BREAKING STRENGTH (POUNDS)		
		W DRILLED HOLE LOCATION		ØB DRILLED HOLE (d)		ALLOY STEEL	CORROSION RESISTANT STEEL	HEAT RESISTANT STEEL
		MAX.	MIN.	MAX.	MIN.			
00	.500					324	140	288
01	.625					500	220	445
02						710	310	631
03						940	420	836
04	.750	.040	.026	.039	.033	1,190	530	1.058
06		.050	.035			1.820	810	1.620
08	.875	.060	.040	.050	.044	2,650	1,180	2,360
3		.065	.045			3.600	1,600	3,200
4	1.000	.085	.065			~~6,200~~ 6,550(h)	2,910	5,820
5	1.125	.104	.084			~~9,850~~ 10,400(h)	4,640	9,280
6	1.250	.123	.103	.067	.061	~~14,900~~ 15,800(h)	7,020	14,080
7	1.375	.141	.121			~~20,200~~ 21,400(h)	9,500	19,000
8	1.500	.160	.140			~~27,000~~ 28,800(h)	12,800	25,600
10	1.750	.198	.178			43,500	20,500	41,000.
12	2.000	.235	.215	.097	.091	63,400	26,100	59,700
14	2.250	.273	.253			86,500	35,600	81,400
16	2.500	.310	.290			113,000	46,400	106,200

(a) "M" MIN. (5 THREAD PITCHES) - REGION OF MINIMUM ENGAGEMENT WITH FULL FEMALE THREAD REQUIRED TO MEET SPEC MIL-F-18240 REQUIREMENTS.
LOCKING ELEMENT WITHIN "M" REGION MUST DEVELOP REQUIRED TORQUE WHEN TESTED IN ACCORDANCE WITH SPEC MIL-F-18240.
LENGTH OR DIAMETER OF LOCKING ELEMENT MAY BE MORE OR LESS THAN "M" PROVIDING ALL OTHER REQUIREMENTS ARE MET.

(b) "N" - ONE (1) COMPLETE THREAD PLUS UNTHREADED PORTION OF END. FOR EASE OF STARTING. LOCKING ELEMENT SHALL NOT BE EFFECTIVE WITHIN THIS AREA.

(c) SCREWS WHICH HAVE A LENGTH LESS THAN THE MINIMUM BASIC THREAD LENGTH, SHALL BE THREADED AS CLOSE TO HEAD AS PRACTICABLE. FOR SCREWS WHICH HAVE A LENGTH GREATER THAN THE MINIMUM BASIC THREAD LENGTH, THE BODY AND GRIP LENGTH SHALL BE IN ACCORDANCE WITH ASME/ANSI B18.3.

(d) DRILLED HOLE DATA IN ACCORDANCE WITH PROCUREMENT SPEC FF-S-86.
PARTS SHALL HAVE DRILLED HEADS IF SPECIFIED BY CODE H.
SCREW SIZES 04 AND 06 SHALL HAVE TWO (2) DRILLED HOLES SPACED 180°.
SCREW SIZES 08 THRU 16 SHALL HAVE SIX (6) DRILLED HOLES SPACED 60°.
(DRILLED HOLES NOT APPLICABLE TO SCREW SIZES BELOW 04).

(e) IDENTIFICATION LETTER "N" IMPRESSED ON THE TOP OR SIDE OF THE HEAD. FOR SCREW SIZES 04 AND LARGER ONLY. TO DENOTE HEAT-RESISTANT STEEL.

(f) THE INTERSECTION OF THE TOP AND SIDE OF THE HEAD MAY BE CHAMFERED OR RADIUSED AT THE MANUFACTURER'S OPTION PER ASME/ANSI B18.3.

(g) THE FILLET SHALL BE IN ACCORDANCE WITH ASME/ANSI B18.3.

(h) MINIMUM BREAKING STRENGTH VALUES ARE BASED ON 180 KSI HEAT TREATMENT. LINED THROUGH STRENGTH VALUES WERE BASED ON 170 KSI.

THIS DRAWING SUPERSEDES ALL ANTECEDENT STANDARD DRAWINGS FOR THE SAME PRODUCT AND SHALL BECOME EFFECTIVE NO LATER THAN SIX MONTHS FROM THE LAST DATE OF APPROVAL SHOWN HEREON.

4 COMPLETELY REVISED

NAS 1351
SHEET 2

REVISION 4 31 May 1996

APPROVAL DATE: APRIL 1962

Aerospace Industries Association

NATIONAL AEROSPACE STANDARD

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
1250 EYE STREET, N.W.
WASHINGTON, D.C. 20005

L SCREW LENGTH (1)	SCREW SIZE																
	00	01	02	03	04	06	08	3	4	5	6	7	8	10	12	14	16
.125	-00-2	-01-2															
.188	-00-3	-01-3	-02-3														
.250	-00-4	-01-4	-02-4	-03-4	-04-4	-06-4	-08-4										
.375	-00-6	-01-6	-02-6	-03-6	-04-6	-06-6	-08-6	-3-6	-4-6	-5-6							
.500			-02-8	-03-8	-04-8	-06-8	-08-8	-3-8	-4-8	-5-8	-6-8						
.625				-03-10	-04-10	-06-10	-08-10	-3-10	-4-10	-5-10	-6-10						
.750					-04-12	-06-12	-08-12	-3-12	-4-12	-5-12	-6-12	-7-12	-8-12				
.875						-06-14	-08-14	-3-14	-4-14	-5-14	-6-14	-7-14	-8-14				
1.000						-06-16	-08-16	-3-16	-4-16	-5-16	-6-16	-7-16	-8-16	-10-16			
1.250							-08-20	-3-20	-4-20	-5-20	-6-20	-7-20	-8-20	-10-20			
1.500							-08-24	-3-24	-4-24	-5-24	-6-24	-7-24	-8-24	-10-24	-12-24		
1.750								-3-28	-4-28	-5-28	-6-28	-7-28	-8-28	-10-28	-12-28		
2.000								-3-32	-4-32	-5-32	-6-32	-7-32	-8-32	-10-32	-12-32	-14-32	
2.250									-4-36	-5-36	-6-36	-7-36	-8-36	-10-36	-12-36	-14-36	
2.500										-5-40	-6-40	-7-40	-8-40	-10-40	-12-40	-14-40	-16-40
2.750											-6-44	-7-44	-8-44	-10-44	-12-44	-14-44	-16-44
3.000											-6-48	-7-48	-8-48	-10-48	-12-48	-14-48	-16-48
3.250															-12-52	-14-52	-16-52
3.500															-12-56	-14-56	-16-56
4.000																-14-64	-16-64
4.500																-14-72	-16-72
5.000																	-16-80

NOTE: SEE CODE FOR ADDITIONAL LENGTHS. (1) LENGTH TOLERANCE SHALL BE AS FOLLOWS:

NOMINAL LENGTH	SIZE		
	0 THRU .375	OVER .375 THRU .750	OVER .750 THRU 1.000
	TOLERANCES		
UP TO AND INCL. 1.000	+.000 -.030	+.000 -.030	+.000 -.050
OVER 1.000 & INCL. 2.500	+.000 -.040	+.000 -.060	+.000 -.100
OVER 2.500 & INCL. 6.000	+.000 -.060	+.000 -.080	+.000 -.140

THREADS: UNRF-3A IN ACCORDANCE WITH PROCUREMENT SPECIFICATION.

MATERIAL: ALLOY STEEL IN ACCORDANCE WITH PROCUREMENT SPEC FF-S-86.
CORROSION-RESISTANT STEEL IN ACCORDANCE WITH PROCUREMENT SPEC FF-S-86.
HEAT-RESISTANT STEEL CONFORMING TO THE CHEMISTRY OF AMS 5731 (UNS S66286) OR AMS 5737 (UNS S66286) COLD WORKED AND AGE HARDENED TO MEET THE FASTENER REQUIREMENTS OF FF-S-86 AND THIS STANDARD.

FINISH: ALLOY STEEL - CADMIUM PLATE IN ACCORDANCE WITH SPEC QQ-P-416, TYPE II, CLASS 2.
- BLACK OXIDE IN ACCORDANCE WITH SPEC MIL-C-13924, CLASS 1.

CORROSION RESISTANT STEEL - CADMIUM PLATE IN ACCORDANCE WITH SPEC QQ-P-416, TYPE I, CLASS 2, EXCEPT POST-PLATE HYDROGEN EMBRITTLEMENT BAKING AND TESTING PER QQ-P-416 ARE NOT REQUIRED.
- SILVER FLASH IN ACCORDANCE WITH AMS 2411.
- PASSIVATE IN ACCORDANCE WITH QQ-P-35.

HEAT-RESISTANT STEEL - SILVER FLASH IN ACCORDANCE WITH AMS 2411.
- PASSIVATE IN ACCORDANCE WITH QQ-P-35.
- BLACK OXIDE IN ACCORDANCE WITH SPEC MIL-C-13924, CLASS 3.
- CADMIUM PLATE IN ACCORDANCE WITH SPEC QQ-P-416, TYPE II, CLASS 2, EXCEPT POST-PLATE HYDROGEN EMBRITTLEMENT BAKING AND TESTING PER QQ-P-416 ARE NOT REQUIRED.

CODE: MATERIAL CODE AFTER BASIC NUMBER. "-" = ALLOY STEEL.
"C" = CORROSION-RESISTANT STEEL.
"N" = HEAT-RESISTANT STEEL.

THIS DRAWING SUPERSEDES ALL ANTECEDENT STANDARD DRAWINGS FOR THE SAME PRODUCT AND SHALL BECOME EFFECTIVE NO LATER THAN SIX MONTHS FROM THE LAST DATE OF APPROVAL SHOWN HEREON.

(9) COMPLETELY REVISED

REVISION (9) 31 May 1996

APPROVAL DATE: APRIL 1962

NAS 1351
SHEET 3

FIRST DASH NUMBER DESIGNATES SCREW THREAD SIZE AS TABULATED.

TYPE CODE AFTER FIRST DASH NUMBER:
"H" = DRILLED HEAD.
"LE" = SELF-LOCKING MALE THREADED FASTENER.
(OPTIONAL TYPE LOCKING ELEMENT IN ACCORDANCE WITH NAS1283).
"LL" = SELF-LOCKING MALE THREADED FASTENER.
(LONGITUDINAL STRIP LOCKING ELEMENT IN ACCORDANCE WITH NAS1283, TYPE L).
"LN" = SELF-LOCKING MALE THREADED FASTENER.
(PELLET LOCKING ELEMENT IN ACCORDANCE WITH NAS1283, TYPE N).
"LB" = SELF-LOCKING MALE THREADED FASTENER.
(PATCH TYPE LOCKING ELEMENT IN ACCORDANCE WITH NAS1283, TYPE P).

SECOND DASH NUMBER DESIGNATES NOMINAL LENGTH IN SIXTEENTHS OF AN INCH AS TABULATED.
TABULATED CODING INDICATES PREFERRED LENGTHS.
ADDITIONAL LENGTHS AVAILABLE ON SPECIAL ORDER, MINIMUM RUN BASIS.
FOR SUCH LENGTHS ADDITIONAL CODING MAY BE ASSIGNED TO LENGTHS IN .0625 INCH INCREMENTS UP TO 3.500 INCHES, AND IN .125 INCH INCREMENTS FROM 3.500 INCHES UP TO AND INCLUDING 6.000 INCHES.

FINISH CODE AFTER SECOND DASH NUMBER:

ALLOY STEEL, "P" = CADMIUM PLATE.
NO SUFFIX FOR BLACK OXIDE.

CORROSION-RESISTANT STEEL, "P" = CADMIUM PLATE.
"S" = SILVER FLASH.
NO SUFFIX FOR PASSIVATE.

HEAT-RESISTANT STEEL, "S" = SILVER FLASH.
"B" = BLACK OXIDE.
"P" = CADMIUM PLATE
NO SUFFIX FOR PASSIVATE.

EXAMPLE:

NAS1351-02-8	= .0860-64 UNRF-3A	SCREW, CAP, SOCKET HEAD, ALLOY STEEL, UNDRILLED HEAD, PLAIN, .500 INCH LONG, BLACK OXIDE FINISH.
NAS1351C04H12	= .1120-48 UNRF-3A	SCREW, CAP, SOCKET HEAD, CORROSION-RESISTANT STEEL, DRILLED HEAD, PLAIN, .750 INCH LONG, PASSIVATED.
NAS1351-08LE16P	= .1640-36 UNRF-3A	SCREW, CAP, SOCKET HEAD, ALLOY STEEL, SELF-LOCKING, OPTIONAL TYPE LOCKING ELEMENT, 1.000 INCH LONG, CADMIUM PLATE, UNDRILLED HEAD.
NAS1351C4LL24P	= .2500-28 UNRF-3A	SCREW, CAP, SOCKET HEAD, CORROSION-RESISTANT STEEL, SELF-LOCKING, LONGITUDINAL STRIP LOCKING ELEMENT, 1.500 INCHES LONG, CADMIUM PLATE, UNDRILLED HEAD.
NAS1351N10LN32	= .6250-18 UNRF-3A	SCREW, CAP, SOCKET HEAD, HEAT-RESISTANT STEEL, SELF-LOCKING, PELLET LOCKING ELEMENT, 2.000 INCHES LONG, PASSIVATED, UNDRILLED HEAD.
NAS1351N12LB36S	= .7500-16 UNRF-3A	SCREW, CAP, SOCKET HEAD, HEAT-RESISTANT STEEL, SELF-LOCKING, PATCH TYPE LOCKING ELEMENT, 2.250 INCHES LONG, SILVER FLASH, UNDRILLED HEAD.
NAS1351N4LB16B	= .2500-28 UNRF-3A	SCREW, CAP, SOCKET HEAD, HEAT-RESISTANT STEEL, SELF-LOCKING, PATCH TYPE LOCKING ELEMENT, 1.000 INCH LONG, BLACK OXIDE COATING, UNDRILLED HEAD.

NOTES:

(1). LOCKING ELEMENT: EXCEPT AS NOTED HEREIN, THE LOCKING ELEMENT WHEN SPECIFIED SHALL BE IN ACCORDANCE WITH SPEC MIL-F-18240.

(2). IDENTIFICATION: MANUFACTURER TO IDENTIFY ALL MINIMUM PACKAGES BY PACKAGE MARKING OF APPLICABLE COMPLETE NAS STANDARD PART NO. IN ACCORDANCE WITH MIL-STD-130.

(3). DIMENSIONS IN INCHES. UNLESS OTHERWISE SPECIFIED DIMENSIONS AND TOLERANCES SHALL BE IN ACCORDANCE WITH FF-S-86, TYPE VI AND ASME/ANSI B18.3.

(4). REFERENCED DOCUMENTS SHALL BE OF THE ISSUE IN EFFECT ON THE DATE OF INVITATION FOR BID.

(5). THIS STANDARD TAKES PRECEDENCE OVER DOCUMENTS SPECIFIED HEREIN.

(6). ADDITIONAL PART MARKING SHALL BE IN ACCORDANCE WITH FF-S-86.

PROCUREMENT SPECIFICATION: FF-S-86: UNLESS OTHERWISE SPECIFIED, CAP SCREWS FURNISHED UNDER THIS STANDARD SHALL BE SUBJECT TO IN-PROCESS CONTROL AND/OR END PRODUCT INSPECTION WHICH WILL INSURE MECHANICAL, METALLURGICAL, CHEMICAL AND COATING OR TREATMENT CHARACTERISTICS WHEN SAMPLED IN ACCORDANCE WITH ANSI/ASQC Z1.4, INSPECTION LEVEL S1, 1% AQL.

REVISION (1) 31 May 1996

APPROVAL DATE: JUNE 1986

(1) COMPLETELY REVISED

NAS1351
SHEET 4

APPENDIX B

FATIGUE ANALYSIS OUTPUT

FATIGUE CRACK GROWTH ANALYSIS

DATE: 10/11/00 TIME: 14:43:08

(Computed: NASGRO Version 3.0.5, Apr 2000.)

U.S. customary units [inches, ksi, ksi sqrt(in)]

PROBLEM TITLE

RC FATIGUE LIFE ANALYSIS

Crack Growth Model: Non Interaction
Equation/Table : NASGRO Equation

GEOMETRY

MODEL: CC02-Corner crack from hole in plate (2D).

```
Plate Thickness, t  =    0.1300
Plate Width, W      =    2.2510
Hole Diameter, D    =    0.2300
Edge to Hole Ctr, B =    0.3300
Poisson s ratio     =    0.33
```

FLAW SIZE: (User specified)

```
a   (init.) =  0.5000E-02
c   (init.) =  0.5000E-02
a/c (init.) =   1.000
```

MATERIAL

MATL 1: 7075-T7351
Plt & Sht; L-T

Material Properties:

Matl No.	UTS	YS	K1e	K1c	Ak	Bk	Thk	Kc	Keac
1	71.0	62.0	41.0	29.0	1.00	1.00	0.130	56.4	

Crack Growth Eqn Constants

Matl No.	C	n	p	q	DKo	Cth+	Cth-	Rcl	Alpha	Smax/SIGo
1	0.348D-07	2.529	0.50	1.00	2.60	2.00	0.10	0.70	1.90	0.30

```
RC FATIGUE LIFE ANALYSIS
MODEL: CC02

FATIGUE SCHEDULE BLOCK INPUT TABLE
----------------------------------
GODDARD SPECTRUM                                         ~

[Note: Stress = Input Value * Scale Factor]

Stress Scaling Factors for Block Case:  1

Scale Factor for Stress S0:   0.68620E-01
Scale Factor for Stress S1:   0.23359
Scale Factor for Stress S3:   0.14214

Schedule info. was input manually

Total No. of Blocks in Schedule =     1

   Block Number and Case Correspondences
 Block Number                  Block Case No.
From   -   To
    1   -      1                        1

Stresses: Tension, bending or pin

---------------------------------
```

RC FATIGUE LIFE ANALYSIS
MODEL: CC02

FATIGUE SCHEDULE BLOCK INPUT TABLE

GODDARD SPECTRUM ~

SINGLE DISTINCT BLOCK

STEP	MATL	NUMBER OF FATIGUE CYCLES	S0 (t1)	S0 (t2)	S1 (t1)	S1 (t2)
1	1	2.00	-100.00	100.00	-100.00	100.00
2	1	4.00	-90.00	90.00	-90.00	90.00
3	1	8.00	-80.00	80.00	-80.00	80.00
4	1	15.00	-70.00	70.00	-70.00	70.00
5	1	49.00	-60.00	60.00	-60.00	60.00
6	1	81.00	-50.00	50.00	-50.00	50.00
7	1	178.00	-40.00	40.00	-40.00	40.00
8	1	641.00	-30.00	30.00	-30.00	30.00
9	1	3120.00	-20.00	20.00	-20.00	20.00
10	1	3405.00	-10.00	10.00	-10.00	10.00
11	1	5019.00	-7.00	7.00	-7.00	7.00
12	1	28853.00	-5.00	5.00	-5.00	5.00
13	1	91655.00	-3.00	3.00	-3.00	3.00

STEP	MATL	NUMBER OF FATIGUE CYCLES	S3 (t1)	S3 (t2)	S (t1)	S (t2)
1	1	2.00	-100.00	100.00	-100.00	100.00
2	1	4.00	-90.00	90.00	-90.00	90.00
3	1	8.00	-80.00	80.00	-80.00	80.00
4	1	15.00	-70.00	70.00	-70.00	70.00
5	1	49.00	-60.00	60.00	-60.00	60.00
6	1	81.00	-50.00	50.00	-50.00	50.00
7	1	178.00	-40.00	40.00	-40.00	40.00
8	1	641.00	-30.00	30.00	-30.00	30.00
9	1	3120.00	-20.00	20.00	-20.00	20.00
10	1	3405.00	-10.00	10.00	-10.00	10.00
11	1	5019.00	-7.00	7.00	-7.00	7.00
12	1	28853.00	-5.00	5.00	-5.00	5.00
13	1	91655.00	-3.00	3.00	-3.00	3.00

Environmental Crack Growth Check for Sustained Stresses
(Kmax less than Keac): NOT SET

RC FATIGUE LIFE ANALYSIS
MODEL: CC02

FATIGUE SCHEDULE BLOCK STRESS TABLE

GODDARD SPECTRUM ~

STEP	MAT	NUMBER OF FATIGUE CYCLES	S0 (ksi) (t1)	S0 (ksi) (t2)	S1 (ksi) (t1)	S1 (ksi) (t2)
1	1	2.00	-6.86	6.86	-23.36	23.36
2	1	4.00	-6.18	6.18	-21.02	21.02
3	1	8.00	-5.49	5.49	-18.69	18.69
4	1	15.00	-4.80	4.80	-16.35	16.35
5	1	49.00	-4.12	4.12	-14.02	14.02
6	1	81.00	-3.43	3.43	-11.68	11.68
7	1	178.00	-2.74	2.74	-9.34	9.34
8	1	641.00	-2.06	2.06	-7.01	7.01
9	1	3120.00	-1.37	1.37	-4.67	4.67
10	1	3405.00	-0.69	0.69	-2.34	2.34
11	1	5019.00	-0.48	0.48	-1.64	1.64
12	1	28853.00	-0.34	0.34	-1.17	1.17
13	1	91655.00	-0.21	0.21	-0.70	0.70

STEP	MAT	NUMBER OF FATIGUE CYCLES	S3 (ksi) (t1)	S3 (ksi) (t2)	S (ksi) (t1)	S (ksi) (t2)
1	1	2.00	-14.21	14.21	-14.21	14.21
2	1	4.00	-12.79	12.79	-12.79	12.79
3	1	8.00	-11.37	11.37	-11.37	11.37
4	1	15.00	-9.95	9.95	-9.95	9.95
5	1	49.00	-8.53	8.53	-8.53	8.53
6	1	81.00	-7.11	7.11	-7.11	7.11
7	1	178.00	-5.69	5.69	-5.69	5.69
8	1	641.00	-4.26	4.26	-4.26	4.26
9	1	3120.00	-2.84	2.84	-2.84	2.84
10	1	3405.00	-1.42	1.42	-1.42	1.42
11	1	5019.00	-0.99	0.99	-0.99	0.99
12	1	28853.00	-0.71	0.71	-0.71	0.71
13	1	91655.00	-0.43	0.43	-0.43	0.43

Environmental Crack Growth Check for Sustained Stresses
(Kmax less than Keac): NOT SET

RC FATIGUE LIFE ANALYSIS
MODEL: CC02

ANALYSIS RESULTS:

Schdl	Block Step	Cycles	Final Flaw Size a	Final Flaw Size c	K max a-tip	K max c-tip
10	1	1330300.	0.00948	0.00959	12.032	12.059
20	1	2660600.	0.01948	0.01973	14.516	14.622
30	1	3990900.	0.03402	0.03534	15.717	16.231
40	1	5321200.	0.05123	0.05617	16.410	17.750
50	1	6651500.	0.07063	0.08509	16.973	19.912
60	1	7981800.	0.09175	0.13024	17.445	23.504

```
FINAL RESULTS:
Crack outside geometric bounds:
c =   0.2154      B - D/2 =   0.2150
at Cycle No.      2302.69
of Load Step No.      9      Description: None
of Block No.          1
of Schedule No.      67
Crack Sizes:  a =  0.114792      , c =  0.215358     , a/c =   0.5330
Total Cycles =  8783260.7
```

```
Execution time (hh:mm:ss): 00:00:01.0
Note: this is elapsed wall-clock time, not CPU time!
```